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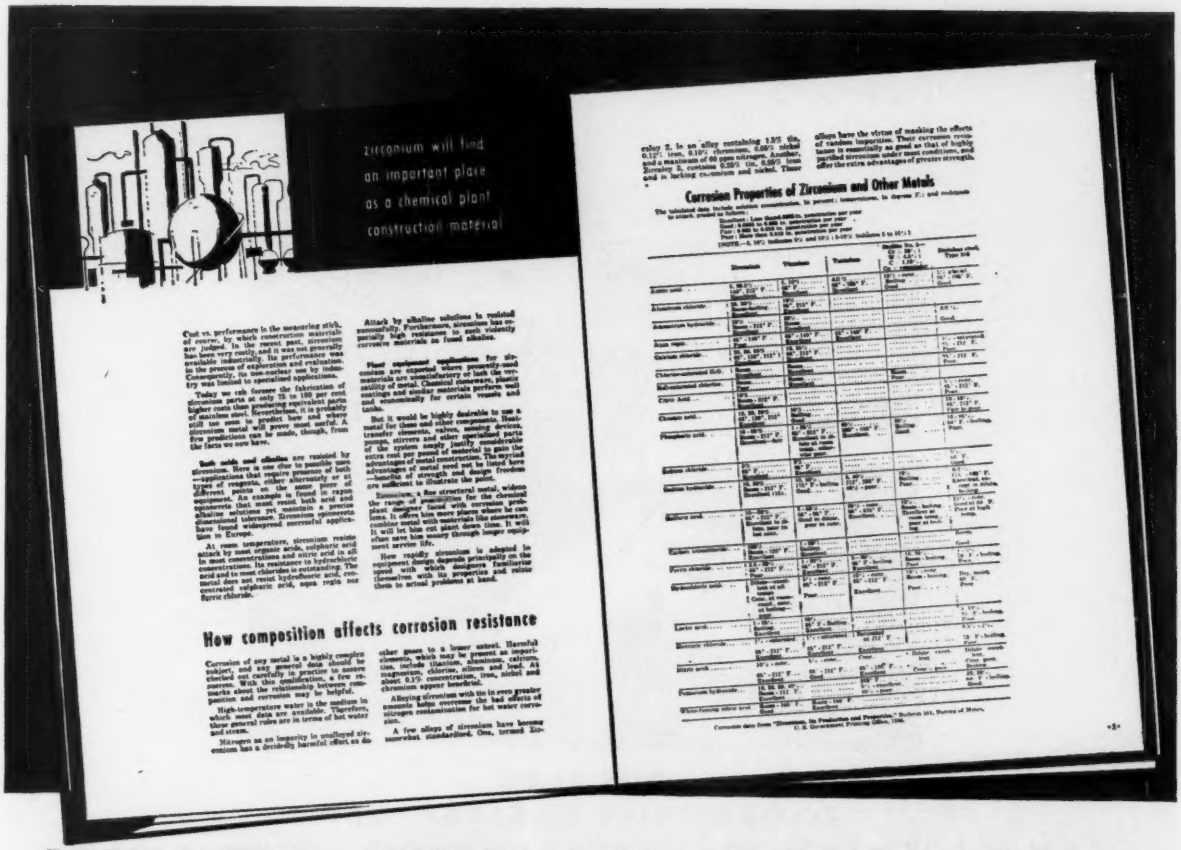
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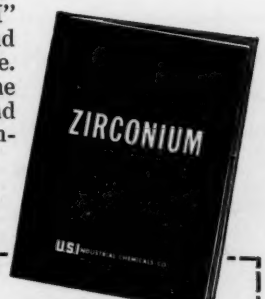

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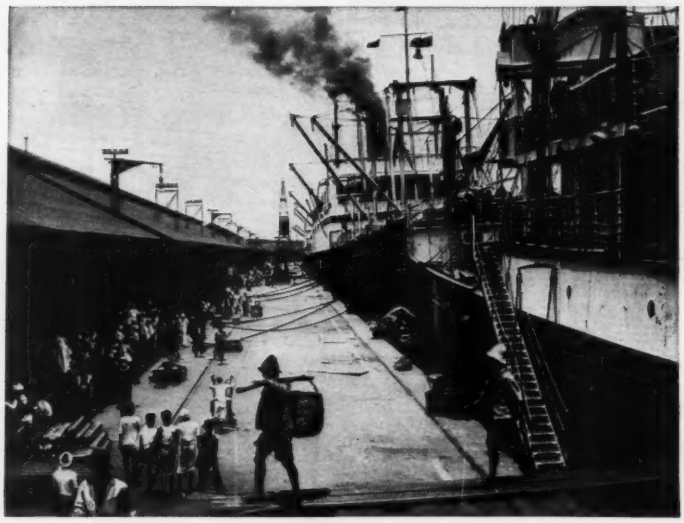

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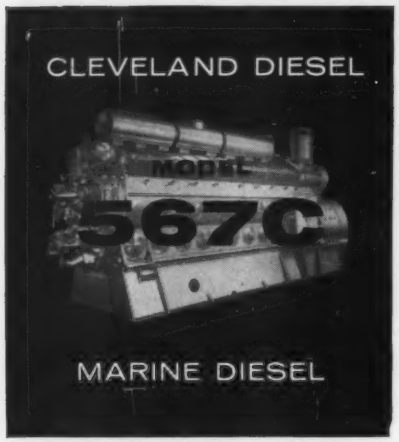

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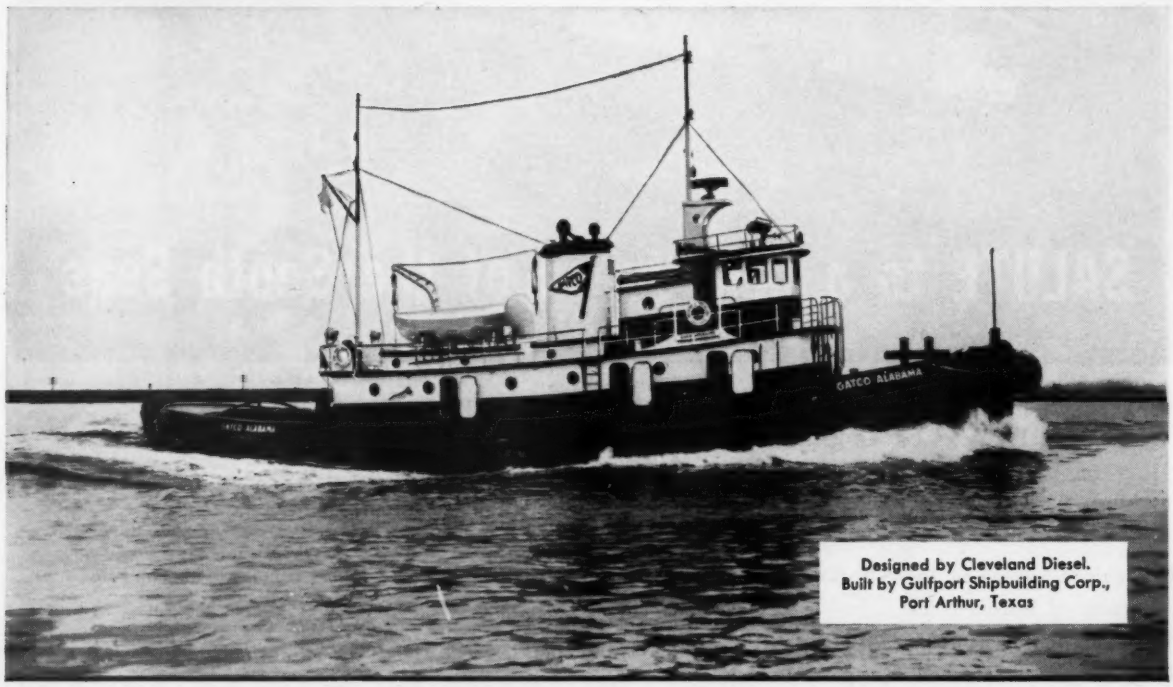

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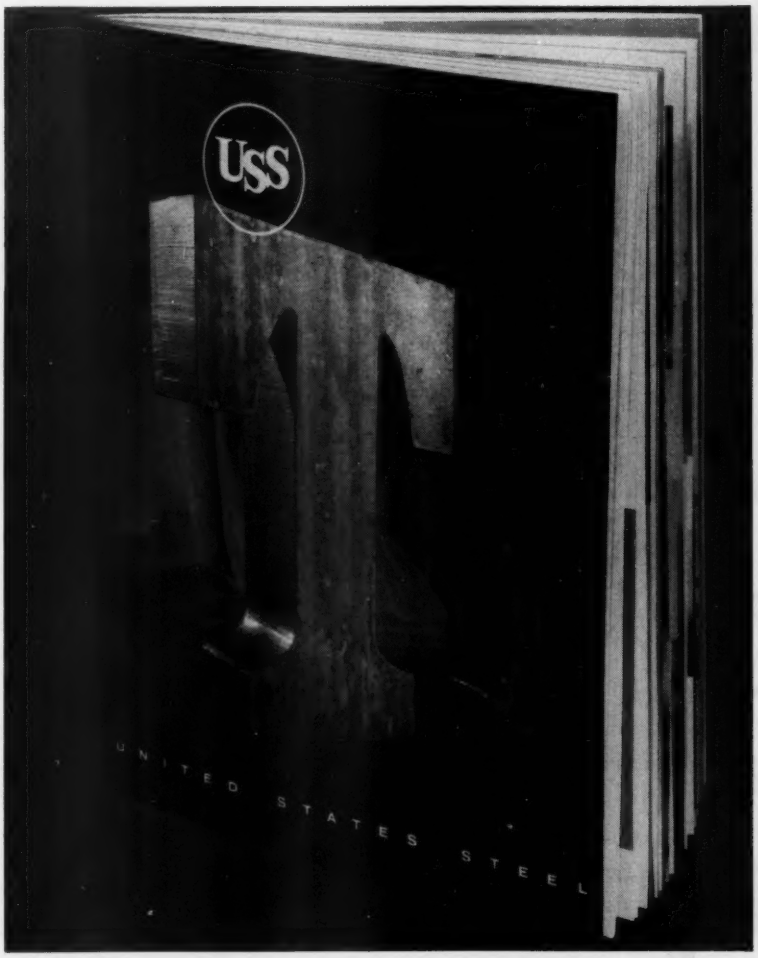

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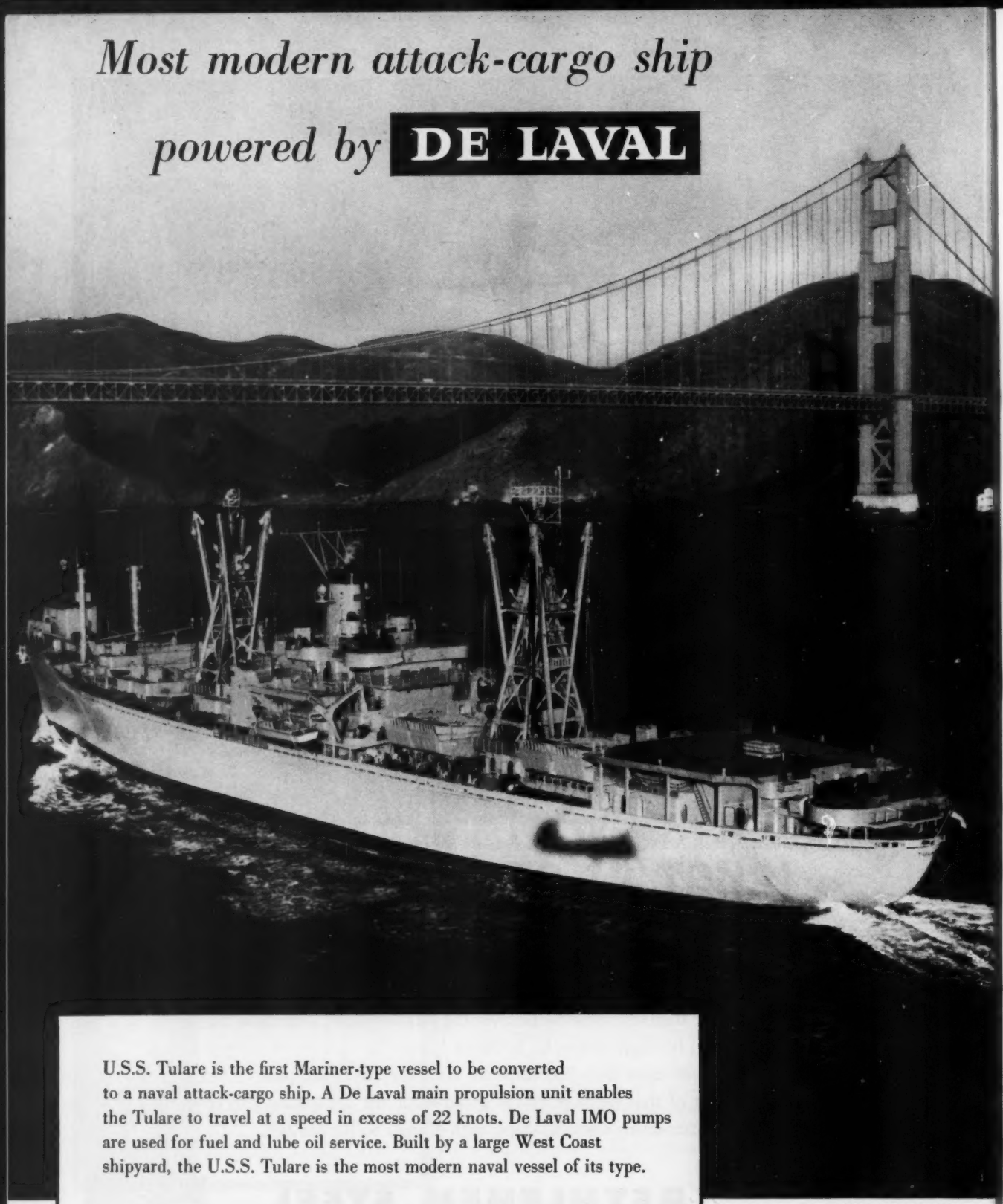

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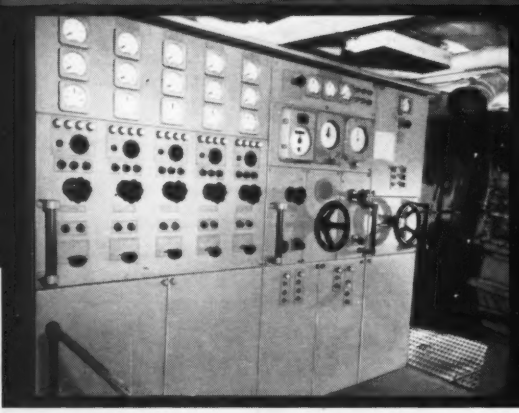

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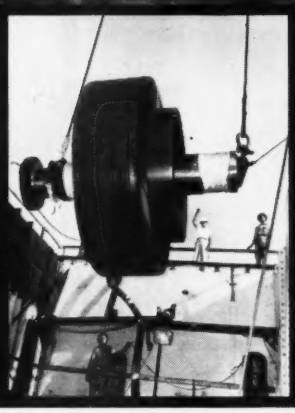
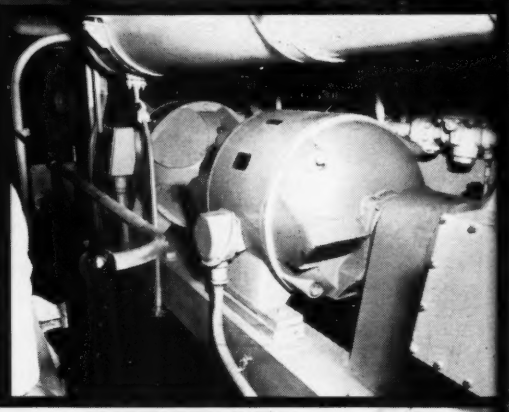


2. 10,500-hp, d-c rotor



3. Propulsion excitation m-g set

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Our engineers worked closely with the Navy and the Ingalls Shipbuilding Company of Pascagoula, Miss., to co-ordinate the design, manufacture and installation of this equipment aboard the Glacier. Westinghouse engineering assistance is at your service any time, anywhere for new or conversion work. Ask for this service by consulting your Westinghouse sales engineer, or by writing: Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pennsylvania. J-92002

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Putting the screws on a tornado

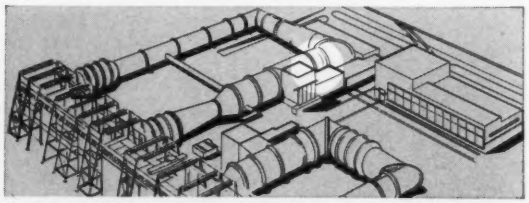
The supersonic wind tunnel under construction at Tullahoma, Tennessee, combines some of the most gigantic construction with some of the most precise electronic controls in the whole history of aircraft testing.

The project simulates conditions of flight in excess of 16 miles altitude, from Mach 1.5 to approximately Mach 4.5. Some of the statistics of design are startling, even in today's world of wonders.

The nozzle walls of the tunnel are solid steel, 100 feet long, 16 feet high. To reach any one of 300 master positions, these plates are moved by 56 huge screw jacks on each side—with a tolerance for error restricted to 8 one-thousandths of an inch in an 8-foot stroke! Each jack "talks back" electronically to Master Control, reporting its position. Provision is made for remote starting and operation by magnetic tape programming, set up in advance.

Two associated companies are doing this job—the Electric Boat and Stromberg-Carlson divisions of General Dynamics Corporation. Electric Boat—builders of the atomic-powered submarines, *Nautilus*, *Seawolf* and *Skate*—has overall responsibility, will supply the jacks and design the servo mechanisms. Stromberg-Carlson is to create and build the digital computer system for the electronic controls.

This project—combining heavy, giant-size, accurate "machinery" with electronic systems of a complex, automated nature—is typical of the service which General Dynamics divisions offer.



Sketch of the project, being built by the U.S. Army Engineers for the U.S. Air Force, Arnold Engineering Development Center. Circled area locates the special walls and nozzle.

S-C STROMBERG-CARLSON

STROMBERG-CARLSON

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CONDENSER TUBE CLINIC

ARTHUR W. TRACY, Metallurgical Engineer, The American Brass Co., Waterbury, Conn.

Some operating factors that affect tube life

COMPOSITION OF THE COOLING WATER

The quantities of cooling water used in condensers preclude any treatment to make the water less corrosive, except where the water is recirculated.

In general, however, plants located inland will have relatively noncorrosive cooling water. Plants situated on tidewater will have corrosion problems, especially if the water is polluted with industrial or domestic sewage and conditions are such that organic matter in the sewage can ferment under anaerobic conditions, with the consequent formation of sulfides. Water in an enclosed harbor or dead-end channel, where the water is more or less stagnant, is particularly subject to infestation by anaerobic bacteria.

PREVENTIVE MAINTENANCE

Frequent cleaning of tubes to remove slimes containing bacteria and the simultaneous removal of sulfide scales will increase tube life. Chlorination of polluted water at frequent intervals, or periodically filling the water spaces in the condenser with chlorine gas, will not only remove the slimes but may also aid in breaking down the unwanted sulfide films which have formed on the inner walls of the tubes.

MEDIA BEING COOLED OR CONDENSED

It is not usually possible to change the corrosive properties of products being handled in the process industries. The venting of noncondensable gases, however, will markedly increase tube life. This is particularly true on the steam side of boiler feed-water heaters and other steam-heated equipment where accumulations of oxygen, carbon dioxide, and ammonia can cause rapid failure of condenser tubes.

TEMPERATURE

The corrosion rate of metals usually increases with increasing temperature. At low water velocities, the formation of gas bubbles on the water side of a tube can initiate pitting which may continue even after the bubble has disappeared. In such cases, a judicious increase in water velocity will insure longer tube life, provided the velocity is not increased to a point where impingement corrosion can occur.

TECHNICAL HELP IN SELECTING TUBES

Your situation may require special consideration and analysis. We are always ready to help and advise in the selection of the right alloy to give best service. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont. 5786B

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Mechanical drawing class of Apprentice School students at Newport News. Those who excel advance to the technical drafting departments.

Shop training scene which shows an apprentice shaping a small die on a shaper, indicates how students are thoroughly trained.

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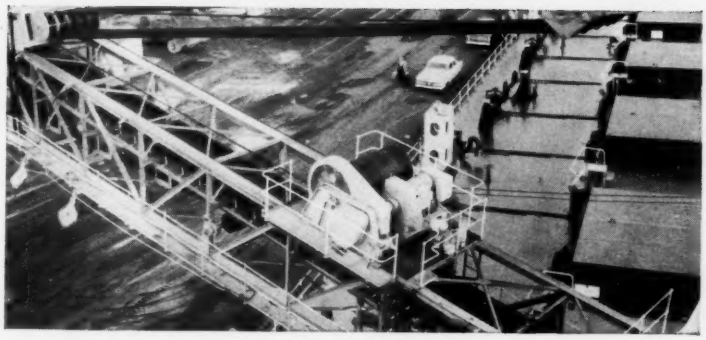
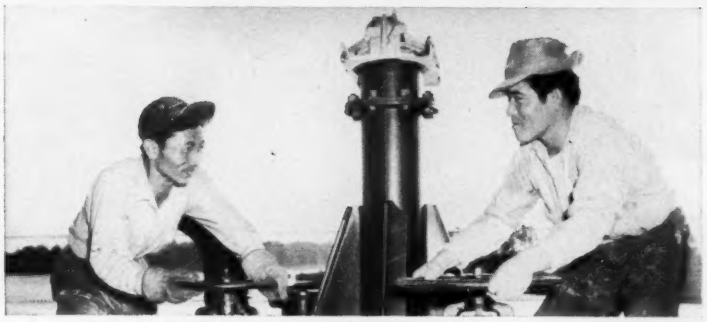


Saves in handling ore: Automatic unloaders carry ore off NBC ships. Monel* alloy pins keep sheaves running free. And Monel ALEMITE® grease fittings in the pins lubricate moving parts. Inside the holds, the gates that control the flow of ore swing on Monel hinge pins.

National Bulk Carriers states

"Monel—a proven money-saver in every division of our ships"

Saves on deck: Large Monel alloy nuts and bolts secure hatches on many NBC ships. Why Monel alloy? Because these fastenings resist marine corrosion ... don't "freeze up." NBC finds Seagoin'* Monel alloy the best material for parts exposed to salt-air and salt-spray corrosion.



Saves in handling oil: The topside sections of reach rods that control flow of oil on tankers are Monel nickel-copper alloy. Shafts and shaft sleeves in fire pump, main and auxiliary circulating pumps, ballast pump and many other pumps subject to salt water and other corrosive material and severe wear are also Monel alloy. NBC finds that *rugged Monel shafting and sleeves last very much longer.*

Saves in ship-handling: Here's S.S. Ore-Convey's anchor windlass. Its smaller shafts are Monel alloy. Its guide blocks and several of its lubricating fittings, too. *The wear resistance of Monel alloy greatly adds to part life.* In NBC tugs, propeller shafts are Monel alloy.

And below decks: National Bulk Carriers standardizes on long-lasting grease fittings of Monel nickel-copper alloy. In feedwater heaters . . . in salt water evaporators . . . valve stems . . . valve trim and in many other engine room services . . . Monel alloy outperforms other metals.

When you need a strong, corrosion-resistant metal to give long, trouble-free service at sea, choose Seagoin' Monel alloy.

INCO TRADE MARK *Seagoin'* **MONEL** *alloy*

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In the radio room of the aircraft carrier Saratoga, operators work with RCA communication receivers.

Photos courtesy of U. S. Navy

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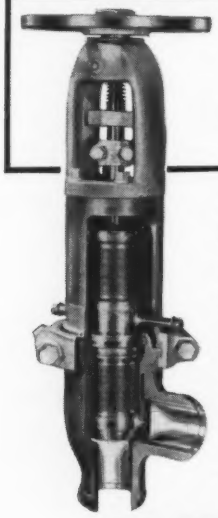

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brings this new look in valves

This is the type of valve found in the engine rooms of the *Nautilus* and the *Seawolf*, and in Navy's plans for added atomic-powered construction. The valve design and application are new, but the brand is well known for dependability.

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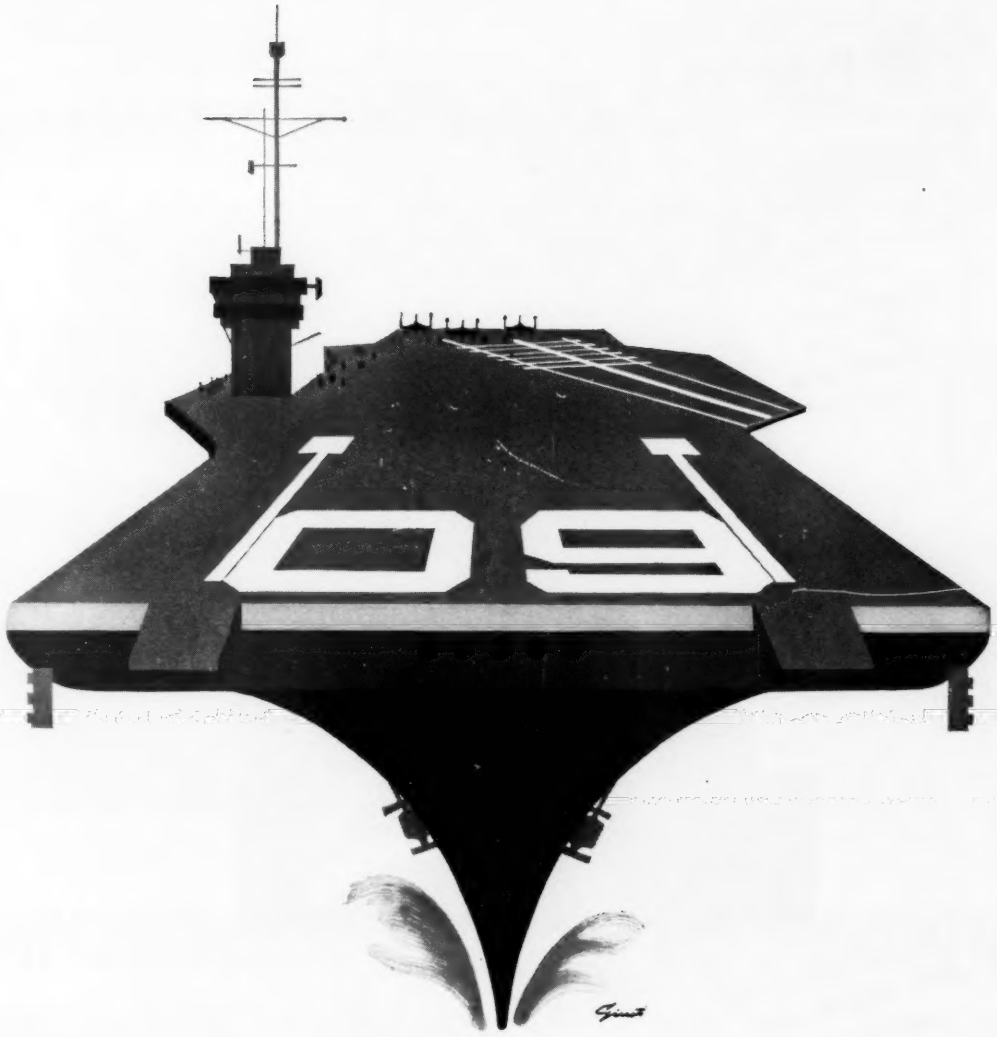

SPECIAL STEELS FOR A SPECIAL LADY

■ The vast hull of the new supercarrier, *U.S.S. Saratoga*, rises from a keel of Lukens high tensile steel plate. Lukens armor plate protects her flanks. Lukens alloy steel forms vessel walls in her vital hydraulic system—holds back the terrific pressure of her boilers. And drums faced with Lukens clad steel stand ready to brake her main shaft. Important jobs in shipbuilding, as in equipment building, often call for the wide variety of special steels . . . and the specialized knowledge . . . Lukens has to offer. Fabricators have long benefited by teaming up with Lukens. This has been going on in shipbuilding, for example, since 1825 when Lukens delivered the plates for the *Codorus*, first iron-hulled steamship ever built.

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LUKENS STEEL COMPANY, COATESVILLE, PA.

World's Leading Producer of Specialty Carbon, Alloy, Armor & Clad Steel Plate • Plate Shapes • For Qualified Equipment Builders

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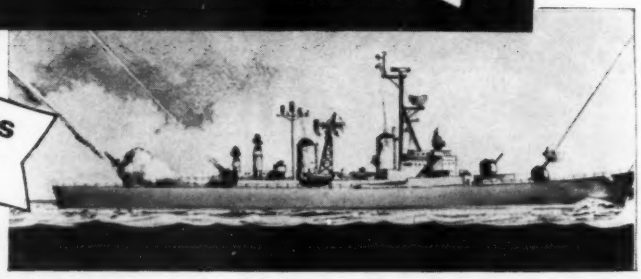
DESTROYERS DD 947 and 948

NEW DLG CLASS FRIGATE

First of its class now under construction



NAVAL POWER is steam power. And this service, more than any other, demands the last word in steam-plant *dependability*. To increase cruising range, boiler *efficiency* is also important.

On *both* counts, Foster Wheeler D Type steam generators have achieved an enviable performance record. That's why they are used on so many different types of vessels—from destroyers to aircraft carriers—tugs to tankers—ferries to passenger ships.

Foster Wheeler means proved *reliability* and *efficiency*—not only in steam generators, but in condensers, economizers and other marine auxiliaries as well. *Foster Wheeler Corporation, 165 Broadway, New York 6, N. Y.*

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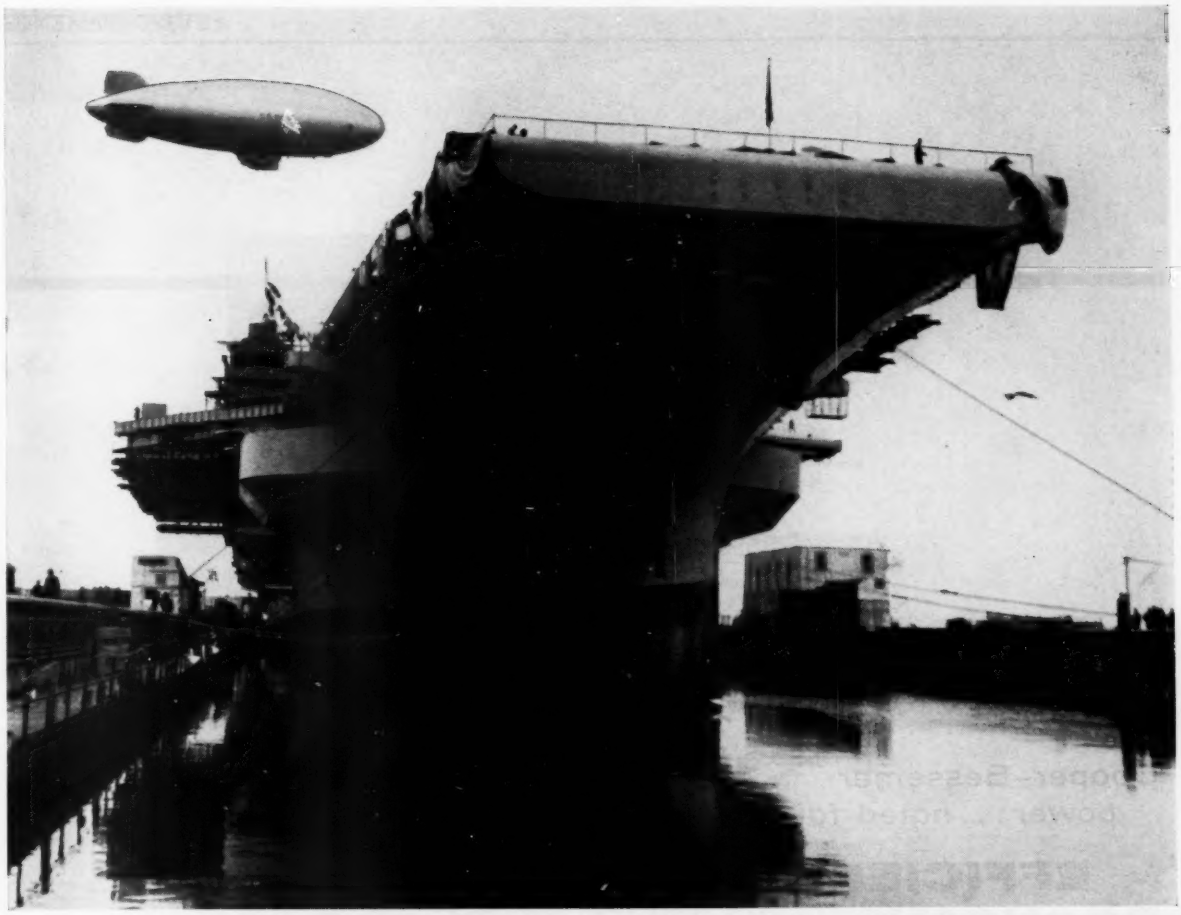
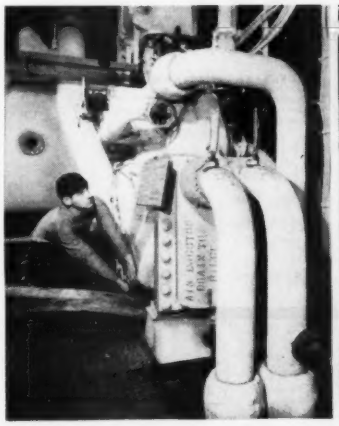
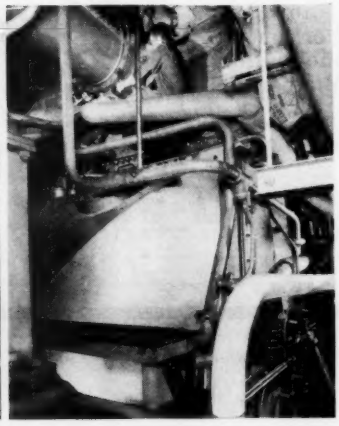


The U.S.S. Forrestal (above) and the U.S.S. Saratoga are both fitted with equipment engineered and built by C. H. Wheeler. The U.S.S. Ranger, the U.S.S. Independence and the U.S.S. Kitty Hawk, now under construction, will also be Wheeler-equipped.

SUPERCARRIERS NEED "SUPER" EQUIPMENT



Vacuum Drain Tank Ejector, built by Wheeler, which has been installed in the U.S.S. Saratoga, sister ship of the U.S.S. Forrestal (above).



Main Condenser (forward) on U.S.S. Saratoga. Nearly all U.S. Navy ships—even atomic submarines and supercarriers—have Wheeler equipment aboard.

The nation's two new "super-equipped" supercarriers now afloat, the U.S.S. Forrestal and U.S.S. Saratoga, contain marine machinery custom-engineered and precision-built by C. H. Wheeler. The three supercarriers which are now under construction, the Independence, the Ranger and the Kitty Hawk, will also use Wheeler equipment.

On the Saratoga are two Wheeler Marine Condensers, which in combination with newly-designed turbines, develop 200,000 horsepower to drive this beautiful 60,000-ton supercarrier in excess of 30 knots. Wheeler Anchor Windlasses, Ordnance Elevators, Capstans, Winches, Auxiliary Gland Exhaust Condensers and Distilling Plant and Vacuum Drain Ejectors are also installed on the 1,040-foot Saratoga.

Marine Division

C·H·Wheeler Mfg·Co·

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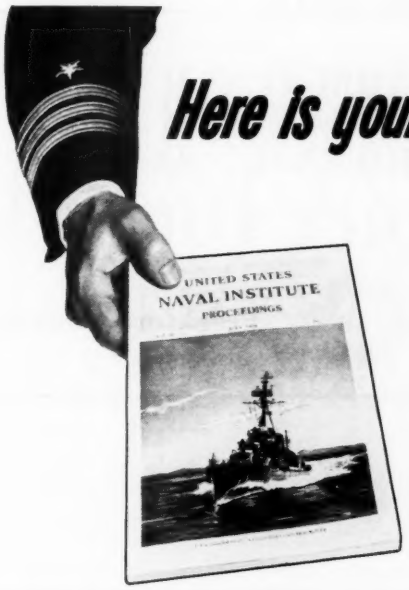

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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 69 AUGUST 1957 NUMBER 3

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SECRETARY'S NOTES

Council Meetings

The Council in 1957 has been extremely active. This Council took charge at a time which has been deemed to be the end of a Society development period and the beginning of a period of stability. This has required active consideration of several important matters which are reported separately below.

Annual Dues

The Council recommends very strongly that the annual dues of the Society be increased from $7.50 to $10.00. This matter is included in a ballot for changes in the By-Laws which is out before the members now.

Included in the Association Notes are financial statements for 1955 and 1956. It will be noted that a substantial loss was sustained each year. As a matter of fact, since World War II the rather substantial reserve which was built up by the increased circulation during the war has been reduced by about $30,000.00. This was done advisedly by the Council.

In 1950 the members approved an increase in dues from $5.00 to $7.50, the first change since the Society was founded in 1888. This was done to offset increased costs at that time. A form of economic stability appeared to be forming in 1950 and it was

believed that this increase would stabilize the Society's finances.

This now proves to have been a too optimistic view. Since the North Korean attack in June, 1950, along with other upsetting influences, prices have continued to rise and although the rate of rise has declined, the upswing is still with us. This issue of the JOURNAL is printed on the same grade of paper which we have been using but it is the costliest paper we have ever used since a new price increase became effective in June.

In addition to rising costs, the Council has initiated certain things which are consonant with the aims of the Society but each of which costs money. These are, and we feel sure that the membership favors all of them:

Improved size and format of the JOURNAL
Junior Membership
A.S.N.E. awards to graduates of Service Academies.

More costly than any of the things mentioned, the Society was forced to rent offices, a thing which was not necessary before 1955. This one item costs the members about $1.00 each per year. It was neither planned nor expected in 1950.

We believe that the membership will approve the increase in dues, which are certainly justified if the Society is to continue to exist at its present level of operation. The ballot count in September will settle this issue.

Changes in the By-Laws

As reported in the May issue, the President appointed a committee to "modernize" the By-Laws. Several changes which had been approved had never been printed in the By-Laws. As a matter of economy, the last printing of these was in 1952, 5 years ago. It was felt that a new printing was in order, but that before this was done, the By-Laws should be examined carefully to assure that they really represented the 1957 American Society of Naval Engineers.

The committee composed of Rear Admiral L. V. Honsinger, U.S.N., as chairman, with Captains Joseph A. Hartman, U.S.N.R. and E. A. Wright, U.S.N., as members, considered the By-Laws very thoroughly and rendered a complete report to the Council. The Council, after full consideration, approved a list of proposed changes which are contained in a ballot now before the members. Previously approved changes and some clerical improvements will be entered in the By-Laws, along with such of the newly proposed changes as are approved, and a new printing will be made and distributed, if possible, with the November, 1957, issue of the JOURNAL.

Society Investments

The committee which was appointed to study and recommend on Society investments has been continued. It was originally an *ad hoc* committee but has now been made the Society's first and only standing committee.

This committee is established to keep a continuing review on the Society's investments. Specifically, its first task was to reach a decision on the investment of $12,000.00, which became available on maturity of Government, Series G, bonds in which it had been invested. Three of the strongest stocks, two common and one preferred are being purchased with this money.

Annual Banquet

The Council decided that there would be an annual banquet in 1958, and that the date would be Friday, 2 May, 1958. The location will be the Hotel Statler, Washington, D.C. Ratio of non-member guests to members will be one to two as in 1957. Other details remain for a Banquet Committee to work out.

Society Awards

U. S. Coast Guard Academy

On 1 June, 1957, Captain George M. Phannemiller, U.S.C.G., representing the Society, presented the 1957 A.S.N.E. award to the Cadet member of the graduating class who was deemed most proficient in Power Engineering. The winner of the award was Cadet John B. Lynn of Clinton, Iowa. The following photograph shows Captain Phannemiller making the presentation to Cadet Lynn.

U. S. Naval Academy

On 5 June, the Assistant Secretary-Treasurer of the Society, Captain Robert B. Madden, U.S.N., represented the Society in making its award at the U. S. Naval Academy. The award was won by Midshipman Franklin F. Alvarez of Monterey Park, California.

U. S. Merchant Marine Academy

On 1 August 1957, Mr. Arthur G. Fessenden, Administrative Assistant of the Society presented the ASNE award for 1957 to Engineer Cadet John A. Greiner of Malvern, N.Y.

Cadet Greiner's selection was based on his outstanding performance in engineering subjects and his potential as a superior Naval Engineer.

The following photograph shows Mr. Fessenden making the presentation to Cadet Greiner.

Brand Award

The annual award which is made by Mrs. Charles L. Brand in the name of her late husband, the 1944 President of the Society, to the Naval Officer who stands first in Course XIII at the Massachusetts Institute of Technology was won in 1957 by Lieutenant Charles D. Crowley, U.S.C.G., who is a member of the Society. The award was made for Mrs. Brand by Professor L. Troost at M.I.T.

The Lamb Award

We have received the accompanying photograph of the Lamb Award which was announced in the May issue. The award was made for 1957 to Ensign William Soland Vorhaben, U.S.N.R., who, of the 1957 graduates who accepted a commission in the U. S. Navy, had the highest combined mutiples for the Departments of Mathematics, Electrical Engineering and Marine Engineering.

Ensign William Soland Vorhaben, USNR.

Errata

This error to be reported can be blamed on no one but the Editor, personally. The nature of it will explain why we are embarrassed.

Under Changes in Membership in the May issue we listed

"Mr. John M. Kirschner as
Manager, Washington Office,
Tube Division
Westinghouse Electric Corporation"

The only mistake in this is that, instead of the company which we gave, Mr. Kirschner is

Manager, Washington Office,
Tube Division
Radio Corporation of America

The address, 1625 K St., N.W., Washington 6, D. C., fits both companies.

Announcements

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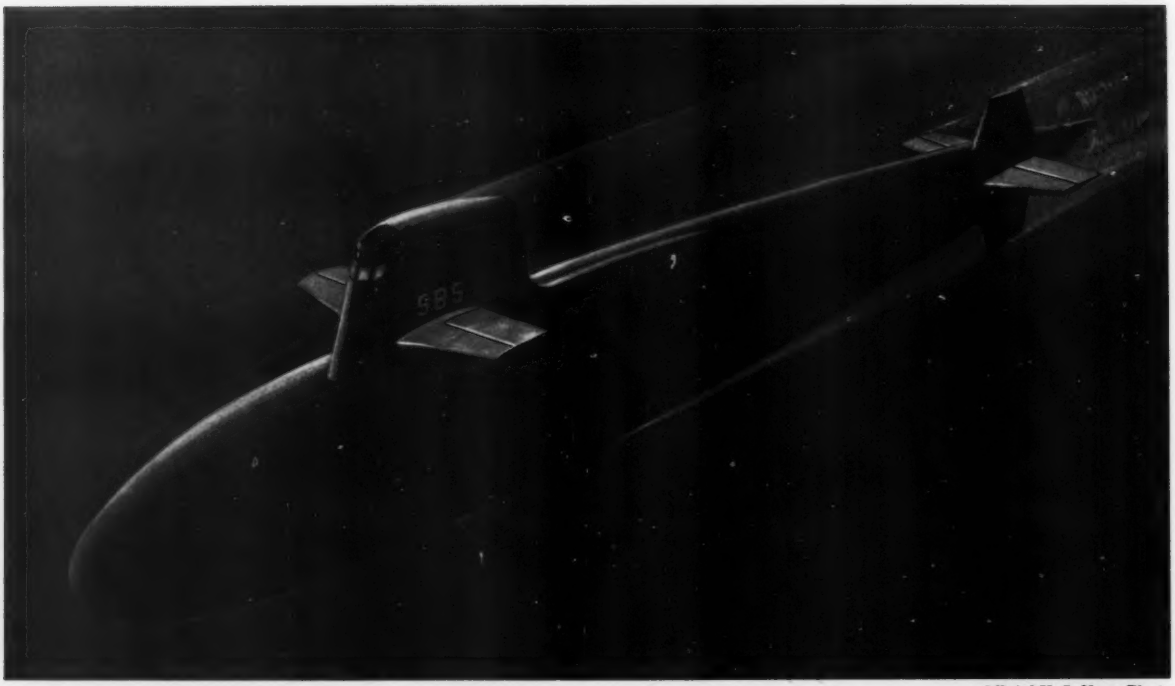
Official U. S. Navy Photo

USS Nautilus **(SS-571) The Navy's First Atomic-Powered Submarine on its initial sea trials.**



Official U. S. Navy Photo

Bow diving planes, normally located on the submarine hull, will be attached to the conning tower of the Navy's newest nuclear sub, *Skipjack* now being built by General Dynamics Corporation's Electric Boat Division in Groton, Connecticut. This first artist conception shows the way the *Skipjack* will appear traveling submerged at unprecedented sustained speed. The *Skipjack* is the first atomic sub designed from the keel up for continuous underwater operations and the newly positioned diving plans will contribute to her stealth and improve her maneuverability. Another feature which leans toward the airplane design is the one-man "Joy Stick" control system.

CAPTAIN ROBERT A. HINNERS, USN, Retired

THE U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY: AN INSURANCE POLICY FOR THE ATOMIC FUTURE

THE AUTHOR

is head of the Luckenbach Graduate School of the Webb Institute of Naval Architecture. He graduated from the U.S. Naval Academy in 1927 and completed the postgraduate course in Naval Construction at Massachusetts Institute of Technology in 1932. After various assignments concerned with design, construction, conversion and repair of naval vessels he served in a research administrative capacity at the David Taylor Model Basin and in the nuclear field as head of the Defense Division of the Armed Forces Special Weapons Project. He was Commanding Officer and Director of the U.S. Naval Radiological Defense Laboratory at the time of commissioning of its new facilities in 1955 and continued in that assignment until his retirement from the Navy in 1956.

THIS IS THE day of organized research. Since it is also the dawn of the nuclear age, a number of major laboratories have been established for the study and development of either military or peace time uses of nuclear energy. Names like Oak Ridge, Los Alamos, Brookhaven, Argonne once found only in fine print on a few maps have become household words in scientific circles, and the general public views them as symbols of both the threat and the promise of the age of the atom.

Not yet so widely known, but equally essential to a well balanced national nuclear research effort, is the one major laboratory which has been established with a sole mission to study the potential hazards of nuclear radiations and develop the means of preventing or minimizing their harmful effects. This is the U.S. Naval Radiological Defense Laboratory, at San Francisco. Its rather formidable name is usually shortened to read NRDL. The approved pronounciation of this short-title, based on common usage, is something which rhymes vaguely with "hurdle."

The officially assigned mission of NRDL begins with a precept to "conduct basic and applied research on the physical and biological effects of hazardous nuclear and thermal radiation, including interrelated effects such as a shock or blast, and the dispersion and contaminating effects of fission products resulting from an atomic explosion or from controlled nuclear processes . . ." In view of the duality of the last phrase, those who wish to look back to the first large scale experimental events which forecast a need for such a laboratory might well choose these two: The first took place in a squash court under the West Stands of Stagg Field at the University of Chicago, where there now is a bronze plate which reads, "On December 2, 1942 man achieved here the first self-sustaining chain reaction and thereby initiated the controlled release of nuclear energy." The second took place at Almogordo, New Mexico on July 16, 1945 which is the date of the world's first nuclear explosion. A number of the scientists now on the NRDL staff contributed in various ways to both of these events. Hence it might be said that their present work at the Laboratory, in a sense, is fulfilling the obligation of a parent to assist in the curbing of an obstreperous offspring.

The foregoing two events made it clear that mankind henceforth, both in peace and war, would have

—Joint Task Force Photo

Figure 1. Water column of Test Baker, Operation CROSSROADS. This resulted from the underwater detonation of a nuclear device having an energy release equivalent to about 20,000 tons of TNT.

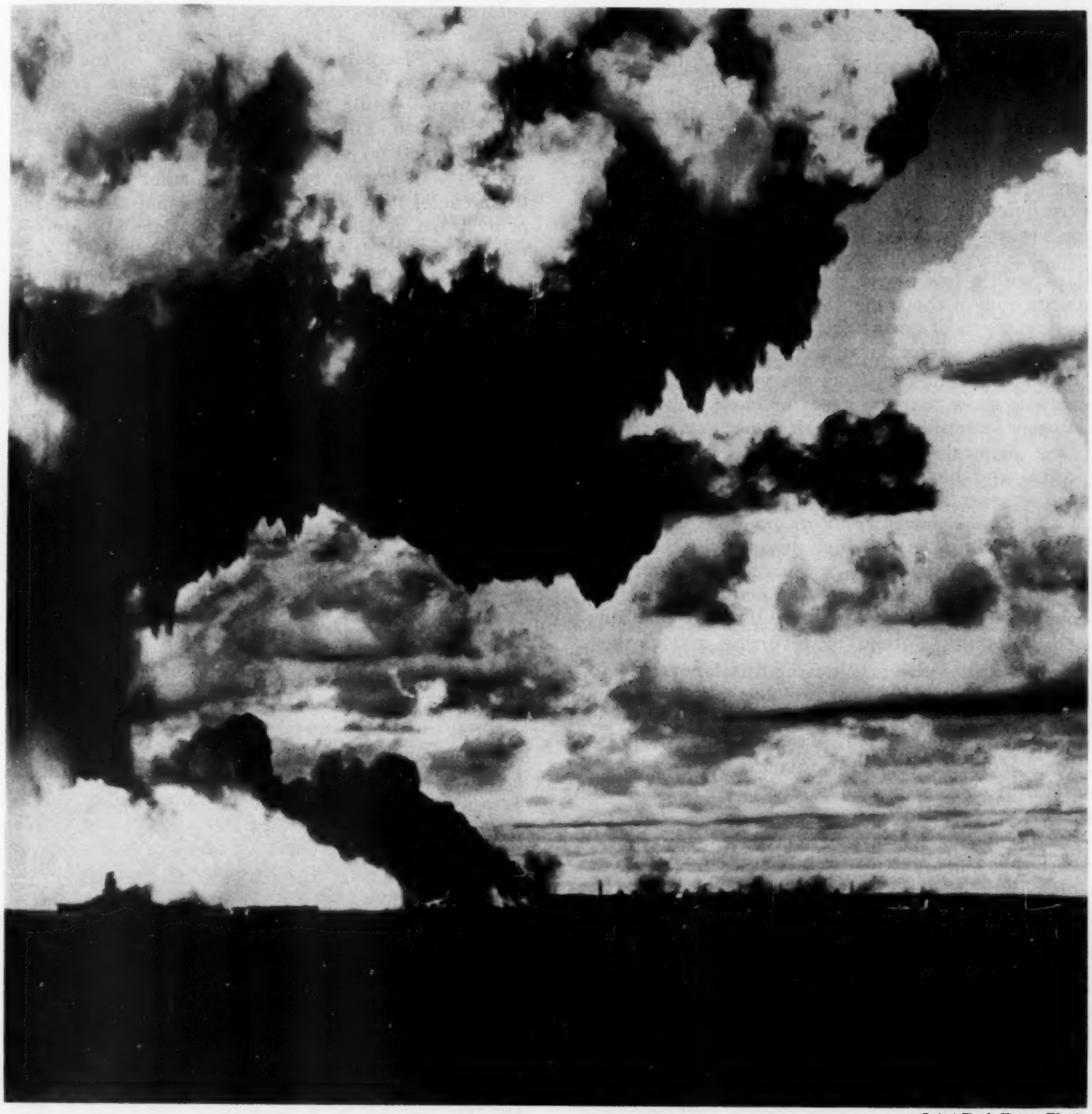
to be prepared to live with nuclear radiation in much greater quantities and potentially more widely dispersed than previously imagined. The discovery that such radiation can cause physical injury had been made many years earlier, having first been noted by early experimenters working with X-rays in 1896. Thus the basic need for a laboratory such as NRDL actually was not created by any specific event, but rather by a long series of scientific and technological developments.

However, there can be little argument as to the event which was the *immediate* cause of the birth of NRDL. This took place at Bikini Atoll on July 25, 1946 when the second of two atomic test explosions (Test Baker of Operation Crossroads) was set off under water and it promptly lifted an estimated million tons out of the ocean in the form of a hollow column about a half mile in diameter and a mile and a half high (Figure 1). Mixed in with this mountain of water were practically all of the fission products of the nuclear explosion. When it came down and, through the resultant rain-out and spray (Figures 2 and 3), delivered those radioactive products to a large number of the target vessels, it created a problem entirely new in naval experience and of sufficient magnitude and complexity to be fully worthy of the initial efforts of a new laboratory. Even before they set sail for the mainland, some of the key Bikini test personnel were discussing the indicated need for the immediate establishment of a laboratory group to start the search for the urgently needed countermeasures. Thus, like Venus, NRDL was born in the foam of the sea.

Once the need for such a laboratory was recognized the necessary steps to bring it into being were taken quickly. It was decided to place it at the San Francisco Naval Shipyard, which is located on Hunters Point in San Francisco Bay near the southern edge of the city. This location had both

—Joint Task Force Photo

Figure 3. NAGATO and several other vessels have been engulfed by the base surge and are about to be further drenched with radioactive fallout directly from the cloud above. The barge-like craft still visible is a floating drydock.



—Joint Task Force Photo

Figure 2. Base surge developing as water column descends. The cloud of spray is rolling outward at a velocity of about 50 knots towards the ex-Japanese battleship NAGATO, in the left foreground.

initial and long-range advantages. It made available the organizational and logistic support of a large existing Naval field activity, including some temporary buildings which could be diverted progressively to the use of the new laboratory as the Shipyard completed its transition from a wartime to peacetime level of operation. Several of the target vessels from Operation CROSSROADS—notably the badly damaged carrier *Independence*—were being returned to San Francisco for examination and were to be berthed at the Shipyard. The proximity of large educational institutions, particularly the University of California and Stanford, was very attractive. This last-named advantage has proven to be a most fortunate one, both in the recruiting of scientific and technical personnel and in enabling the staff to maintain the continuing professional contacts which are so important to those working in a rapidly expanding new scientific field. Although there are times when it cannot be denied that the Laboratory envies some of its sisters in their more remote locations in deserts or on hill-

tops, on the whole the foresight of those who chose the San Francisco location has been vindicated.

The Laboratory was formally established as an official "project" of the Bureau of Ships on 18 November, 1946, only a few months after the completion of CROSSROADS. Initially its staff consisted of about a dozen junior Naval officers who had served as radiological monitors at Bikini. They still were being kept very busy in monitoring the various vessels returning from that operation. Therefore, it is not suprising to find from the records that along with a few geiger counters, scalers and other instruments of the trade (mostly borrowed), one of the first items of permanent equipment acquired by the infant laboratory was a coffee urn.

It is significant that from the very start, the records also show that the need for close collaboration between scientific and technical personnel trained in the physical sciences and those drawn from the medical and biological sciences was clearly recognized as essential to the accomplishment of the mission of the Laboratory. For example, the initial Bureau of Ships letter which directed the San Francisco Naval Shipyard to set up a "laboratory for radiological studies" and outlined the intended scope of the program, further informed the Shipyard that "the Bureau of Medicine and Surgery also will utilize the facilities of this laboratory for making studies of physical radiological hazards and such work in connection therewith as is associated with decontamination." This marriage of the physical and biological sciences proved to be an unusually fruitful one, for reasons that will be brought out later.

A number of tasks awaited the newly formed laboratory. An obvious one was the thorough exploration of possible techniques for the removal of radioactive contamination from various types of surfaces. Another was to undertake a comprehensive evaluation of existing types of radiation detection and measuring instruments and then assist in the development of some that would be more satisfactory for military field use.

However, even more important than these applied research problems was the need for putting the whole question of atomic defense, and especially its radiological aspects, into proper perspective. It is true that with the greatly increased capacity for mutual self-destruction in war created by the ability to wrap so much devastation into a small package, it already had been recognized that the only completely satisfactory "defense" would be to achieve a new measure of world-wide political stability and international control—sufficient to make impossible the use of atomic weapons or any other comparable aggregate of instantaneous destructive force. More than a year before the establishment of NRDL, on 15 November 1945 the President of the United States and the prime ministers of Great Britain and Canada had issued a joint statement pointing up the need for "effective reciprocal and enforceable safeguards acceptable to all nations against the use of atomic energy for destructive purposes." Largely on the initiative of the U. S. Government, attempts to initiate these controls were begun within the United Nations organization early in 1946. The subsequent earnest but unsuccessful efforts on our part to establish such a system are too well known to require further comment in this article. It is sufficient to note that the passage of over ten years finds the negotiations still underway—a rate of progress which hardly could be considered commensurate with the thousand-fold increase in weapon yield which was achieved during this same period.

In the lack of any such international harmony and in the face of growing evidence that potential enemies were succeeding in producing their own atomic weapons, it became increasingly urgent that we explore and develop all possible defensive measures concurrently with the development of our retaliatory offensive atomic power. It was in connection with these protective measures that a need for proper perspective arose. What about our ships? On the whole the Navy observers at the Bikini tests were encouraged by the fact that, contrary to the dire predictions of the uninformed, the two test explosions stopped far short of wiping out the target fleet. However, there still were some who viewed the extensive physical damage wrought on a limited number of these closely spaced, unmanned "sitting duck" targets and wondered audibly whether the surface Navy of the future ought not to consist entirley of turtle-backed, streamlined monsters designed primarily for maximum blast resistance. It is undoubtedly true that in some such manner a ship could be designed to remain intact several hundred yards closer to the point of an atomic detonation, but at the sacrifice of most of the other military and sea-going qualities which are the very reasons for her existence.

No implied criticism of either the planning or execution of operation CROSSROADS is intended in the foregoing. It was indeed a remarkable achievement, carried out under most difficult conditions, and the compact spacing of the target vessels was skillfully planned to give gradations of damage just as in a laboratory experiment. But some persons failed to realize it was just that—"the largest scale laboratory experiment in history"—and that the close spacing of the target ships was not representative of the cruising formations of a task force at sea, nor were the very limited damage control measures undertaken at Bikini comparable with those that would be accomplished on manned ships under wartime conditions.

However, even though the possibility of wiping out an alert and properly dispersed task force by means of a single atomic blow was refuted by the CROSSROADS results, this test operation also was equally convincing in pointing up a new requirement for all units of the fleet, if they were to be adequately prepared for an enemy attack by nu-

clear weapons. This was the need for developing means by which vessels physically undamaged by a nearby contaminating* nuclear detonation could protect themselves against the more far-reaching radiological effects.

On the biological side, there were questions of equal urgency. Most of the data and protective techniques available concerning radiation exposure were based on control of the occupational hazards of persons required to undergo repeated exposures to relatively small amounts of radiation, such as radiologists, X-ray technicians, radium dial painters, or workers at AEC production activities. In general, the available biological data covered radiation dosages much smaller than those of immediate military significance. More information, obtained under properly controlled conditions and with a sufficiently broad base to be statistically reliable, was needed concerning the effects of single large doses or repeated doses of moderately large size. Furthermore, because of the time lag usually asociated with the development of the more acute effects of serious radiation exposures, it was urgently necessary to develop data and means by which a commander, either afloat or ashore, could estimate reliably the number and extent of both his own radiation casualties and those of an enemy, and the probable length of the time lag or "latent period" involved. Such information could be of very personal and immediate military importance (Figure 4). It is not always sufficient merely to draw a circle on a map and say, "Everyone not adequately sheltered within this circle will become a radiation casualty." The answer to that type of over-simplification was well stated by the Marine Officer who retorted, "That may be so, but it isn't going to help me any if I get shot *now* by an enemy soldier who received his lethal dose of radiation a half hour ago but isn't going to find it out until next week!"

—Defense Dept. Photo (Marine Corps)

Figure 4. U.S. Marines coming in under an atomic cloud during tactical maneuvers at the Nevada Proving Grounds. The helicopters are being used to "leapfrog" the troops past a radioactive area.

The newly formed laboratory group promptly attacked the radiological defense problem on both the physical and biological fronts. On the physical side, one of the first matters to be looked into was decontamination. The improvised, emergency efforts at cleaning up the radioactive ships, which had been undertaken with varying degrees of success at Bikini after Test Baker, needed to be reduced to precise laboratory experiments with adequate control of the many variables involved. This was done by designing and constructing exposure chambers in which small test panels could be contaminated. These panels covered the wide variety of surfaces ordinarily found on board ship—freshly painted, weathered, bright, dull, rough, smooth, etc. They were sprayed by remote control with laboratory-prepared mixtures of radioactive and inert compounds representative of the fission products resulting from an atomic explosion.

The panels then were used as specimens for trying out various methods of decontamination, in which the test conditions again were controlled as carefully as possible. The importance of this can be illustrated by citing a common error which has been made, particularly under field test conditions. This is the procedure of merely using the relative amounts of radioactivity, measured on the surface "before and after" with an instrument, as an index of the decontamination efficiency of some particular agent or method. If the contamination is relatively fresh and heavy, and is contained mostly in a covering of dirt or surface film, almost any method can achieve a high *percentage* of removal and would therefore be adjudged "good." If, on the other hand, the contamination is lodged firmly in the pores of the material in microscopic sizes, the same method will accomplish a very much smaller percentage of removal and might be adjudged "poor." Hence the importance of accurate control and knowledge of the initial conditions of each test, a point which always has been stressed at NRDL.

The purposes of the panel tests were several-fold. One obvious one was to determine whether the standard paints currently used on ships were reasonably resistant to radioactive contamination. The results showed that they are, if maintained in good condition. Another was to determine what special equipment or chemicals, if any, might need to be carried on board ship or maintained on shore for decontamination purposes. Here the results showed that, at least for large-scale use, there is little need for any fancy chemical or brand name; any good household detergent is an adequate adjunct to the all-important copious water and elbow grease However, these results refer to relatively impervious surfaces such as painted steel. Porous substances such as unpainted wood or concrete present quite

* The term "contaminating" nuclear burst is used to refer to one detonated on or below the surface of the earth or water, as distinguished from one set off sufficiently high in the air to eliminate heavily contaminated fallout patterns.

different problems. They cannot be discussed in detail here, but as in the case of many other results of NRDL's work, the answers are available in technical reports and manuals for those who require them. As for extremely porous and absorbant materials such as Manila lines, test results show that if they ever become thoroughly drenched with radioactive contaminants it is a waste of time and effort to try to reclaim them—they've "had it."

An important extra dividend, from the ship-protection standpoint, which grew out of the laboratory decontamination tests was the demonstration of the very high degree of protection which could be obtained by pre-wetting the topside surfaces with fresh salt water prior to the arrival of significant quantities of the radioactive contaminants. This was a key step in the development of the washdown system which has become the fleet's principal countermeasure against radioactive fallout.

It would not be correct to leave the impression that NRDL's work and experience in decontamination was confined entirely to laboratory-scale studies. The battered Bikini target ship *Independence* (CVL 22) was used as a full-scale guinea pig following its arrival at San Francisco Naval Shipyard in the spring of 1947. Not only was it used for actual decontamination tests, but also as a proving ground to check out the adequacy of techniques being developed to prevent the spread of contamination by personnel whose duties required them to work alternately in "dirty" and "clean" areas. The successful outcome of this work on the *Independence*, together with the continuing help of the natural process of radioactive decay, soon produced one result which could hardly have been anticipated by those who had gingerly towed her into San Francisco Bay in a restricted, quarantined status. Before long the ship itself was providing badly needed additional laboratory space through utilization of areas which had not sustained serious blast or fire damage. The *Independence* continued in this role until she was finally disposed of in 1952. Thus the first of the CVL's rounded out her distinguished World War II career by bequeathing to the Navy valuable data on the effects of the weapons of the future, first as a target ship at Bikini and finally as a laboratory ship at San Francisco.

After the initial decontamination tests on the *Independence*, NRDL followed up the full-scale part of its efforts in this field through participation in atomic weapons tests in Nevada and Eniwetok. Some of the work was done out at the Proving Grounds and some back at the Laboratory using test panels which were exposed to fallout and flown back to San Francisco while still relatively "hot." Further opportunities to acquire full-scale experience and data also came through emergency calls. One of these was in January of 1950 when a radium capsule was ruptured at the Radiological Defense school on Treasure Island and the resultant contamination was tracked through the greater part of an entire building before the accident was discovered. By assisting in the clean-up job, the Laboratary acquired valuable data on the decontamination of wood and concrete surfaces. Then, early in 1953, NRDL received an emergency call from Canada via the AEC. The world's first reactor accident had just taken place at the atomic energy installation at Chalk River, Ontario. Due to a control failure, some of the fuel rods had overheated and ruptured their containers. The resultant contamination of both the building and the reactor was particularly troublesome to handle because of a combination of hazards. Some indication of the magnitude of the problem is given by the estimate of the Canadians that about 10,000 curies of fission products had been washed down into the reactor basement. This was equivalent to more than six times the radioactivity of all the radium that had been produced in the world up to that time.

Arrangements were made to have NRDL personnel participate in the job of dismantling and decontamination of the Canadian reactor. Many months were required to accomplish it without undue hazard to personnel. The outcome was entirely successful and later developments showed that the part played by NRDL representatives had provided them with not only valuable data on methods for dealing with this type of emergency, but also some international goodwill.

The earlier work of NRDL on the general problem of contamination and decontamination of surfaces has been described in some detail in the foregoing because it is of "historical" interest in being the first major area of investigation which was assigned to the Laboratory, and also because it is a rather good example of the variations and complexities encountered in each aspect of the radiological defense field. However, this is only one component of the much broader program which had to be undertaken in order to carry out the basic mission quoted earlier. It was soon recognized that along with the specific, short-term projects of an applied nature that are customarily assigned to a military laboratory by its sponsors, only a thorough and systematic investigation of all of the important factors producing and influencing radiation hazards would provide the Armed Services with the data needed for dealing with them. This is the more scientific approach to so complex a problem. It is the one for which the NRDL scientists consistently have argued, and which they have tried to follow to the maximum extent possible within the overall limitations of funds, facilities, and the sometimes more urgent demands of an immediate and specific question. The scientific approach may take somewhat longer, but in the end can be expected to yield results applicable to a wide range of situations instead of only those corresponding to a few random tests.

Here again, an example drawn from the field may help to illustrate the importance of the systematic approach. Most of our field data concerning radioactive fallout necessarily have been obtained either

at Eniwetok or in Nevada. Fallout measurements and contamination studies made in these respective localities, once they have been repeated several times and found to be fairly consistent, certainly are of value when predictions are needed as to radiological conditions which would be encountered after a similar nuclear explosion at Nevada or Eniwetok. But how reliable are they if the explosion is of the contaminating type and takes place in an entirely different environment? Unfortunately, neither the desert sands of the Nevada Proving Ground nor the coral fragments of Eniwetok and Bikini atolls are very representative of many of the kinds of targets of vital concern to military and civil defense. We are equally interested in the situation which would exist after a nuclear detonation in a typical harbor containing thousands of tons of soft, sticky mud, or on a land area covered with lush vegetation, or in the midst of a forest of either trees or skyscrapers. Data obtained in Nevada or Eniwetok, which must be considered essentially empirical in nature because of its localized character, cannot be lifted with assurance and applied to these other environments without well-considered qualification or adjustment. Such data *can* be put to good use elsewhere if it is properly adjusted and extrapolated as a result of a careful and systematic study of the mechanism of fallout and contamination production and of the probable interactions between the surrounding environment and the fission products, beginning with the incandescent state of their first formation. That is a job to be done in a laboratory as well as in the field, and one which cannot be done superficially if one wants assurance that no important variables have been overlooked. Also, it requires the joint efforts of scientists of several different disciplines, especially the chemists, physicists and biologists. It is one of the jobs underway at NRDL.

A convenient way to cover the highlights of the present NRDL program, and at the same time introduce the major components of the Scientific Department is to enumerate some of the work in terms of the organization of this Department. It is comprised of three major divisions and a staff group. These are:

(1) *The Nucleonics Division.* This is staffed chiefly by physicists and electronic scientists. The Division is concerned with studying the characteristics of the nuclear radiations peculiar to both detonations and controlled chain reactions and of the thermal radiations associated with nuclear detonations. It conducts basic studies in nuclear radiation shielding, in the effects of nuclear and thermal radiations on materials, and it also designs, develops and evaluates radiation detection instruments. As examples of applications of its work, its shielding studies are expected to lead to better methods for estimating the worth of the radiation protection provided by the structural and other components of a ship, and its instrument studies are pointing the way towards radiation detection instruments which will give data in terms more representative of the actual biological hazard. This latter investigation is a joint effort with personnel of the BioMedical Division.

(2) *The Chemical Technology Division.* This is staffed mainly by radiological chemists and chemical engineers, together with a limited number of physicists and mechanical engineers. This Division is concerned with the phenomena and mechanisms involved in the creation, transport, deposition, and expeditious removal of radioactive materials. This requires considerable study of the physical, chemical and radiochemical properties of these substances. Examples of applications of its work are the decontamination and environmental studies previously described. In connection with these, NRDL radiological chemists have developed some extremely precise radio-chemical techniques which permit accurate identification and analysis of very minute samples of nuclear debris.

(3) *The Biological and Medical Sciences Division.* This Division conducts field tests and laboratory investigations of the biological effects of ionizing and thermal radiation, including the development of methods of diagnosis and treatment of radiation injury and means of protection against it. Not only basic investigation is carried out, but also experimentation oriented to the solution of problems arising from field tests. The Division participates with other units of the Laboratory and other naval laboratories, with the Atomic Energy Commission and with the Armed Forces Special Weapons Project in biologic investigations connected with the detonation of nuclear weapons. It supports the other divisions in their research and analytical programs, and maintains close liaison with biological and medical research workers both in the U. S. and abroad, with exchange of results and information concerning experimental techniques. The investigations at NRDL are based chiefly on controlled experiments with small animals for which the Laboratory maintains its own animal colony for breeding and storage of the required special strains. One example of progress is the fact that laboratory animals can now be made to survive radiation dosages regarded as lethal a few years ago. Also, substantial amounts of radioactive material absorbed internally can now be eliminated by prompt treatment. The BioMedical Division is staffed chiefly by civilian scientists representing various biological disciplines covering the fields of biochemistry, physiology, psychology, pharmacology and biophysics. The majority of the laboratory technicians are naval enlisted personnel. There are also several medical officers qualified in research. The Division is in a state of readiness for participation in field emergencies as well as the planned field test programs.

(4) *The Military Evaluation Group (MEG).* This is staffed by persons chosen to provide a variety of scientific skills including physicists, chemists, mathematicians, engineers and operations analysts. The

individual members also are selected on the basis of an aptitude for correlating and integrating the work of others. This group has several important functions. One, which is performed in a staff capacity to the Scientific Director, is to carry on a continuing study of the results of the work of all of the other scientific groups in the Laboratory and evaluate their findings with particular reference to their military significance and use. A second, which is related to the first, is to maintain close liaison with outside laboratory groups and agencies doing related work or having related interests, and to correlate their results with those of NRDL. A watch is kept for gaps or uncertainties still requiring attention. This is intended to assist in keeping the overall laboratory program vital and to establish a stimulating internal regenerative cycle. As might be expected, these functions sometime lead to honest and healthy differences of opinion between the personnel of MEG and the other Divisions. These are resolved around the conference table.

A third function of the Military Evaluations Group is performed in an operating rather than a staff capacity. This is to draw from and integrate the results of the work of the other more specialized groups of the Laboratory and translate it into a form directly useable for military operational reference or planning. Such work is usually presented in the form of manuals, surveys or systems analyses. Since radioactivity has no more respect for one type of uniform than another, and since the effects of an attack by nuclear weapons can be sufficiently widespread to cut across a number of military and civil jurisdictions, it is not surprising that this part of the Laboratory's work in particular has found use throughout all of the Armed Services. Examples are portions of the Radiological Defense Manual which was prepared for the Armed Forces Special Weapons Project, and another entitled "Radiological Recovery of Fixed Military Installations" which is currently in use by all three of the Armed Services. Similar work is in process on that part of the Bureau of Ships manual which deals with the radiological recovery of ships, and studies made by NRDL played a key part in the formulation of the U.S. Navy Passive Defense Manual. Special surveys of the vulnerability of various types of military installations to nuclear attack also have been made for several different Service agencies.

In making studies such as the foregoing, the experience of the Laboratory has led to an increasing recognition of the importance of the methods of Operations Analysis in approaching radiological defense problems. The NRDL personnel concerned have been given special training and have developed a competence in this technique. In questions of atomic defense it should hardly be necessary to stress the need for systems analysis, or full consideration of the overall problem as well as its component parts. Yet it now seems clear that in the earlier days there was too much of a tendency to assume that as soon as a man had a Geiger counter in his hand, he was fully prepared for an atomic attack. No Geiger counter has ever stopped any significant quantity of radiation by itself, and in the absence of a well-trained, realistically decentralized disaster-control organization with the requisite emergency communications and equipment, a Geiger counter can be nothing more than a first-class panic producer. To cite another example, drawn from an NRDL study which has received considerable recent recognition in Civil Defense planning, it is not sufficient to have a shelter or evacuation program barely adequate to insure initial survival. A realistic analysis of the probable overall radiological situation indicates that the survivors must have a substantial reserve capacity to accept additional radiation dosages for accomplishing essential recovery operation. This must be taken into account in the initial planning.

In the execution of the scientific program it frequently is necessary to cut across precise organizational lines. An individual project or study often is assigned to a small task force, in which the leader and respective members have been selected to provide the particular assortment of scientific knowledge and engineering and technical skills required for the case in hand. In such instances, the project as a whole is identified with the Laboratory Division having the maior interest for general administrative purposes, but the individual members are free to derive technical support and guidance from other NRDL specialists in their own fields. under the overall coordination of the program leader.

Because of this tendency of much of the work to cut across lines and not confine itself to traditional academic disciplines or single sponsoring agencies, the formal summaries of the NRDL program are customarily arranged under a list of "areas of investigation" in which work is being carried on. This list, in itself, constitutes a compact summary of the program as a whole. The current one is as follows:

NRDL PROGRAM AREAS

1. Characterization of Radiological Phenomena
2. Development of Radiological Models
3. Nuclear and Physical Chemistry
4. Contamination Phenomena
5. Countermeasure Development for Ships
6. Countermeasure Development for Land Based Construction
7. Effects of Nuclear Radiation on Inanimate Matter
8. Nuclear Radiation Characteristics
9. Nuclear Radiation Shielding
10. Radiological Physics
11. Radiac Research and Development
12. Radiac Engineering
13. Analysis and Evaluation of Radiac Systems
14. Thermal Radiation Characteristics
15. Effects of Thermal Radiation on Materials and their Properties
16. Biological Aspects of Hazard Evaluation with

Particular Reference to Critical Organ Effects of Ionizing Radiation
17. Effects of Penetrating Ionizing Radiation upon Biological Systems during the Acute Phase
18. Persistence of Injury due to Penetrating Ionizing Radiations—Delayed Effects, Late Effects, Life Span Changes and Genetic Effects
19. Diagnosis, Prophylaxis and Therapy of Radiation Injury
20. Internal Radiation Hazard
21. The Effects of Radiation upon Performance and Behavior
22. Appraisal of Situations and Effectiveness of Countermeasures
23. Direct Evaluations for Sponsoring Agencies
24. Fundamental Studies and Experimentation in Radiation, Radiation Effects and Radiological Defense
25. Special Techniques, Methods and Instrumentation

The foregoing summary indicates the broad scope of the research effort which has evolved at NRDL during the past ten years. It also suggests that the development and prosecution of a program of this magnitude must have required the construction of some specially designed physical facilities, outstanding in their diversification and flexibility. Such facilities have indeed been acquired, but they did not come easily and are the result of several kilotons of intensive planning and persuasion both in San Francisco and in Washington.

The old-timers at NRDL can now recall with some amusement the desperate efforts of the staff to find the type of shelter and environmental control needed for precise experimentation, as the work load expanded again and again beyond the capacity of the two small rooms originally occupied in 1946 and the additional improvised spaces later assigned. By 1953 the still-temporary facilities of the Laboratory had grown to 20 different buildings or structures, and a more heterogeneous assortment can hardly be imagined. Only a few of these—a radiochemical laboratory, a "hot cell," change house and a temporary animal colony shelter had been specifically designed and constructed for their respective functions. The others included one substantial four story building (a wartime shipyard shop), several converted wooden barracks, two quonset huts, a Butler hut, and a couple of just plain shacks of the type to be found in the moraine of every wartime expansion. One small but rather valuable acquisition was a left-over World War II brig (of the guardhouse, not seagoing variety); this was gratefully occupied by some biological experimenters who were looking for a quiet, secure place with plenty of shielding for their animals. Another interesting component of the laboratory complex was a surplus barge which had been converted for decontamination experiments, for which its built-in tanks were valuable as sumps which could be isolated from the ordinary local drainage. Thanks to the proximity of one of the world's largest cranes and an understanding shipyard, this particular barge has spent most of its NRDL career on dry land where it can provide a more steady platform for chemical balances and other precision instruments. Hence it may possess some claim to fame as the world's first amphibious laboratory.

Even more frustrating than the temporary and makeshift nature of most of the facilities was the excessive dispersion. Division heads found their personnel scattered among as many as five separate buildings, and the whole set-up was unfavorable to the cross-fertilization between disciplines essential in this type of endeavor. However, by this time relief literally was in sight in the form of the steel skeleton of a fine new laboratory, and weekly reports of the builder's progress were published in the NRDL *Bulletin* as an aide to morale.

Construction of this new Laboratory, an $8,000,000 project, had commenced in 1952 and had signified recognition by the Department of Defense and the Congress of the need within the Armed Services for a more permanent major research facility which could give priority consideration to the radiological problems resulting from military uses of nuclear energy. A location was chosen near the southern entrance of the San Francisco Naval Shipyard, where a portion of the Hunters Point area was earmarked for proper development of the new Naval Radiological Defense Laboratory.

In the design of the permanent facility, in addition to a careful study of other recently constructed research laboratories, full use was made of the experience of a number of the NRDL staff members who had participated in the development of techniques for working with radioactivity at Oak Ridge, Los Alamos, the Radiation Laboratory of the University of California, and elsewhere. Completely windowless construction was decided upon for a number of reasons. It offered considerably more useable floor and wall space (estimated at about 25 percent) for the same overall cost and size, and also better environmental control for precision measurements where steady ambient temperatures, uniform illumination and dust-free air are essential. It also offered considerably more resistance in the event of an enemy attack in the area, not only against direct blast and fire damage but particularly against the entry of radioactive contamination through broken windows. If the latter were to occur, the resultant rise in the radioactivity background count would play havoc with many of the research programs. However, the question of interruption due to enemy attack does not preoccupy the minds of the NRDL personnel. This is because after some years of study of the probable effects of many different kinds of atomic attack on various land areas, it is the feeling of the staff that if it has not accomplished that portion of its research work which concerns basic military and civilian defense planning *before* the attack occurs, it will be too late to do much about it afterwards. This also is reflected in a

Figure 5. Main building of the U.S. Naval Radiological Defense Laboratory in San Francisco. Completed in 1955, it is considered to be one of the world's most modern and best equipped nuclear laboratories.

Figure 6: Nuclear accelerator building at NRDL. The Van de Graaff generator is located on the second floor of the two-story portion, with the heavily shielded target room directly below.

continuous effort to try to look five to ten years ahead in formulating the overall NRDL program, so that by the time prospective new weapons such as intercontinental ballistic missiles with thermo-nuclear warheads are in the possession of a potential enemy, the changes in defensive techniques necessary to meet these new threats will already have been worked out and disseminated.

The new main building is 400 x 100 feet and six stories in height (Figure 5). Vertical transportation is provided by two-way escalators, which made it possible to consolidate the various storage, issue and service facilities without undue loss of transit time by persons using them. There is an auditorium seating approximately 300 persons at the sixth floor level, and an isotope receiving and issue room with suitable shielded pits and overhead crane, on the ground floor level. The ground floor also houses the major shops and other activities requiring heavy floor loads. Several heavily shielded rooms are located at various points to house the major irradiation facilities, and the biological research rooms on the fifth floor are finished in tile and specially ventilated to an extent approaching hospital standards. Throughout the remainder of the building, the wall partitions are of the movable metal type to provide flexibility for changing conditions. The hoods used for radio-chemistry contain special features designed to minimize the possibility of spread of contamination through spills or blow-backs; these were developed at NRDL and proof-tested in the previous temporary chemical laboratory. The principal management offices, library, photographic service, and similar general functions are located on the third floor in order to provide easy accessibility to and from all parts of the laboratory.

To avoid any objectionable effect of the lack of windows on the occupants, the interiors were given special color treatment based on earlier Navy

Figure 7. Target room of the accelerator building, showing a physicist adjusting the position of the beam with respect to the target. The outside door, which is a four-foot slab of concrete hydraulically operated, can be seen in the background.

studies related to submarine habitability design. An additional antidote for claustrophobia is the rooftop cafeteria, which has large picture windows overlooking San Francisco Bay. This provides a mid-day break which nourishes the soul as well as the body. However, the NRDL staff members have found that when there is plenty of work to do one soon becomes oblivious to the absence of wall openings and even welcomes the freedom from the distractions of changes in light and temperature which so often accompany windows, especially when they admit direct sunlight.

In addition to the main building, a separate annex with heavier shielding houses the Laboratory's two million volt Van de Graaff type nuclear accelerator (Figure 6). A noteworthy feature of the design of

this building is a 4-foot thick concrete door in the target room (Figure 7) which can be rolled aside to permit the beam to emerge into a fenced-in enclosure against the hillside, for scatter experiments.

The laboratory buildings are well supplied with the research tools of modern physics, radiochemistry, biology, and developmental engineering, including such items as high intensity gamma radiation sources and X-ray machines, scintillation spectrometers, multi-channel differential analyzers, high speed calorimeters and bolometers, ultracentrifuges, numerous varieties of radiation counters, spectrographs, spectrophotometers, electron microscopes, climatic simulators, master slave manipulators, and engineering equipment. Service outlets at laboratory work spaces include AC and DC power, compressed air, distilled water, vacuum, steam and natural gas.

The completion of the move to the new buildings in 1955 brought the total plant value of the Laboratory to about $12,000,000 exclusive of land. Aside from the direct impact of these more adequate facilities on the problems in hand, the management staff also welcomed this material assistance in the task of recruiting and holding the specialized personnel required for the Laboratory's mission. In these days of scientific and technical personnel shortages, a closely knit, highly qualified research laboratory staff is not easy to acquire or replace. Altho it does not appear directly as book value, NRDL's possession of a competent, diversified scientific task force "in being" should be regarded as its most valuable asset.

On a typical work day, a visitor to NRDL's main laboratory building with the time and justification for a general look through all six of its floors might afterwards describe his tour about as follows: After signing in and being issued a visitor's badge which serves both for identification and as a carrier for a radiation exposure film badge, he first was escorted

Figure 8. Glassblowers at work on radiochemical apparatus. They are using special lathes in which flame jets take the place of cutting tools.

Figure 9. The self-service store. It is conveniently located on the second floor of the main laboratory building.

to the main shop area and found work underway on fallout sampling instruments for a forthcoming atomic weapons field test. Since these instruments must operate by remote control, he learned that the initial flash of radiation from the detonation often is used to actuate the trigger which starts the mechanism.

Nearby in a first floor laboratory containing a cobalt 60 irradiation source, the visitor saw experimental measurements underway to determine the effect of the interaction of the body of the operator on the accuracy of a gamma radiation monitoring instrument. For this purpose the "body"—which was mounted on a revolving turntable—was a full-scale masonite dummy designed by the Naval Medical Research Institute, the material having been chosen to give an accurate simulation of human tissue so far as radiation absorption and scattering effects are concerned. In another large laboratory space at the other end of the first floor, he saw tests in a large spray booth of a stripable plastic coating intended to facilitate decontamination of surfaces previously treated with it. Here a well known advertising slogan might be reversed to read "Remove the surface and you remove all."

Taking an escalator to the second floor the visitor paused to watch the glass-blowers shaping the intricate contours of some chemical apparatus (Figure 8), and down the hall he saw a "customer" checking out the items needed for a new project from the self-service laboratory supplies store, (Figure 9), where the users can select what they need from stocks fully displayed in the manner of a modern super-market. Also on the second floor he found the health physicists preparing plans for radiological safety ("radsafe") support of the next field operation, in between answering calls for routine laboratory monitoring. In the nearby Engineering Services Branch, a design man was preparing layout plans for an instrument trailer and vainly trying to convince a physicist that there *is* some

Figure 10. Apparatus used for shielding studies. In the foreground is a gamma radiation source with its beam directed towards a thick steel slab. The heavy cylinder in the rear houses a spectrometer which is measuring the scattered radiation emerging from the rear of the slab. The results are analyzed and recorded in the instrument panels on the left.

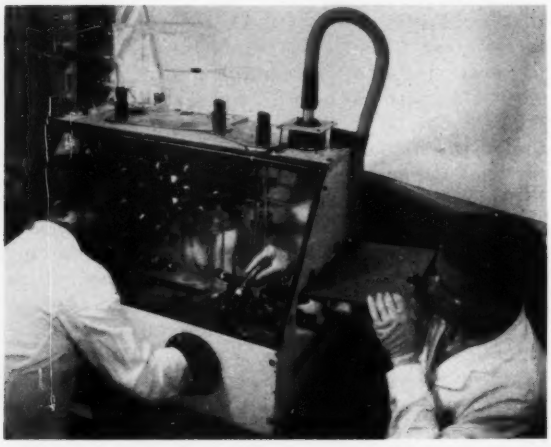


Figure 11. Apparatus used for airborne radioactivity inhalation experiments. The glass bottles contain laboratory-bred mice. The biologist at the left is demonstrating the use of a "glove box," in which manipulations can be made while maintaining a protective gas-tight envelope. During actual operation, the door at the end would be closed and sealed.

ultimate limit to the amount of equipment, including power supplies, that can be crowded into so small a space.

Up in a third-floor conference room, the visitor found a joint meeting underway between a team of NRDL scientists and program officers and a visiting group from another agency which had come to compare and analyze results from the last field test. Across the hall in the Comptroller's office several persons were putting together an intricate budgetary report for Washington, and in another room nearby two program officers were working on a field test time schedule, trying to figure out how to compress a normal eight or nine months of preparatory work into five. In one of the branches of the Military Evaluation Group, a conference was underway concerning the best way to present a radiological recovery scheme in a new manual. The Commanding Officer was on the long distance telephone inquiring about the laboratory facilities program, and the Scientific Director was presiding over a lively session of the Research Planning Council. The one relatively quiet spot on the entire third floor was the reading room of the technical library.

Upon ascending to the fourth floor the visitor found himself in a different kind of world where the problems were of the scientific rather than the management variety. Here in the Nuclear Radiation Branch he found two physicists and an electronic scientist checking the performance characteristics of a newly developed mobile gamma ray spectrometer. Designed for field use, this instrument was intended to provide accurate information as to the energy spectrum of the gamma radiation existing in a radioactive fallout field—data which are needed both for radiac instrument design and for assessment of probable biological damage. In an adjacent laboratory, he found another gamma ray spectrometer being used to determine the energy pattern and directional characteristics of the gamma rays emerging from the back side of a thick steel slab (Figure 10). Elsewhere on the fourth floor, tests of the inflammability of forest fuels were underway

Figure 12. Ion exchange columns, used for separation of rare-earth elements in the radiochemical laboratory.

under simulated atomic heat flash in the thermal radiation laboratory, and across the hall the solid state physicists were studying the results of damage produced in a dielectric material by previous irradiation with the Van de Graaff accelerator. In the instrument branch an electronics engineer and a technician were assembling a transistorized model of a gamma radiation survey meter.

When he moved on up to the fifth floor, the visitor found that he frequently needed an interpreter, as he was an engineer and not accustomed to auditing discussions about such things as taurines, serum lipoproteins and hematopoietic syndromes. Here he also encountered some well-caged rats which had been irradiated in varying amounts and were being checked for subsequent willingness and ability to perform work in a squirrel cage wheel fitted with a mechanical counter. In another room he found a display of autoradiographs (so called because the radioactive specimen is made to take its own photograph by placing it in contact with a photographic plate). These had been made from tissues and bones of sacrificed animals, showing how certain long-lived radiosotopes such as strontium 90 tend to concentrate in the bones after entering the body through inhalation or ingestion (Figure 11). He learned that these tests were preliminary to other work underway on methods of preventing or eliminating such deposits. In still another laboratory he saw a rather complicated array of glass tubing through which a dark liquid was being circulated in a series of pulsations. He was told that this was making it possible for a rat liver to remain "alive" and continue to function entirely outside the sacrificial animal to which it had recently belonged. He learned that such studies of living isolated organs are throwing much light on the mechanism of radiation injury, the understanding of which is an important prerequisite of the development of better methods of treatment.

Proceeding to the sixth floor the visitor stopped first to observe the activity of the liquid in a row of glass and resin ion exchange columns, (Figure 12), whereby fractional separation and collection of the eluent, the difficult process of separating chemically similar radioactive nuclides, which required many weeks of laborious fractional crystallization in the days of Marie Curie, was being accomplished in a few hours. Another powerful separation tool in use was an ultrafilter, in which colloidal particles as small as a 100 millionth of an inch could be filtered out by forcing the liquid suspension through cellophane membranes under high pressure. Radioactive samples concentrated by one of these methods finally were taken to a radiation counter for measurement and identification of the activity. For use as a shortcut method, especially valuable for short-lived isotopes, there were multichannel analyzers in which a minute radioactive sample could almost be made to write its own signature in the form of an energy spectrum. Also on the sixth floor, the visitor saw chemists assisting the biologists by performing radiochemical analyses of tracer amounts in biological specimens, including tests designed to throw more light on the properties and subtle behaviour of some of the internally administered protective substances.

By this time, the visitor was pleased to learn that one final short flight of steps would take him to the rooftop cafeteria for a cup of coffee and a view of San Francisco Bay before making his departure.

Field tests have played an important part in the NRDL program for the past ten years, particularly those conducted jointly by the AEC and the Department of Defense in the Nevada and Eniwetok Proving grounds. In recent years, the test operations have come along with such pressing regularity that for many of the NRDL participants the Nevada desert valleys and Western Pacific atolls have long since lost the glamor which those exotic areas might once have had for the occupants of a windowless laboratory. They agree fully with the Washington visitor who, when shown the Nevada Proving Grounds for the first time, said it looked like just the place to throw away used razor blades.

Preparations for field operations are painstaking events, as delicate instruments often tend to balk in the presence of too much sand or salt water and all needs for special tools and spare parts must be carefully anticipated. The general attitude of the NRDL staff towards the nuclear weapons field tests is that participation in them is necessary and important as a means to an end—the end being, wherever possible, to obtain whatever full scale data are needed to permit subsequent reliable laboratory *simulation* of radiation and contamination effects. This approach is technically sound, as in most cases the conditions essential to accurate experiments can be achieved much better in the laboratory where there are fewer variables and better controls.

A good example of this technique is found in the study of the effects of *thermal* radiation from nuclear explosions, a field in which NRDL has done extensive work for a number of different agencies. First, instruments were developed in the laboratory for accurate measurement of the intensity and spectral characteristics of the radiation. These had to cover higher intensities and more rapid variations in the thermal flux than any that were commercially available, since the demands to be placed on them were far beyond those of any thermal measurements ordinarily made in industry or even in other research applications. The instruments then were taken to the Proving Grounds and exposed during nuclear tests of various yields and at a number of different distances. With the data thus obtained, the physicists returned to San Francisco and tackled the development and construction of laboratory devices which would accurately simulate this radiation.

The laboratory apparatus thus evolved consists of a family of several thermal radiation "sources" which are used for different purposes, depending

on the needs as to target area and precision of control. Two of the sources consist of ordinary searchlights, one 60″ and one 36″ diameter, obtained from surplus military stocks. These are set up to function in the usual manner, except that after the parallel beam of light and heat rays has traveled only a few yards it is refocussed by a second parabolic reflector similar to the one in the searchlight. The purpose of this arrangement is to produce a small, intensely hot circular area at the target station with temperatures comparable with those of the carbon arc, but with a field of practically uniform intensity and free from the physical interference of the electrodes.

Figure 13. Mitchell thermal source. This device produces, over a small circular target area, thermal radiation intensities equivalent to those resulting from a wide range of nuclear detonations and target distances.

A third NRDL thermal source, which is utilized as the primary one because of the flexibility and accuracy of its controls, consists of a large Mitchell carbon arc projector of the type used for background projection in the motion picture industry. To this the Laboratory physicists have added an optical system which reduces the size of the projected beam to a single "hot spot" about the size of a dime. The intensity of the thermal flux is very uniform throughout this small area, and furthermore can be controlled with time by means of a shutter which consists of two rotating, overlapping discs with cam-type contours (Figure 13). This shutter was specially designed at the Laboratory to reproduce the shape of the "pulse" of the heat flash produced by the detonation of an atomic weapon. Provision also is made for insertion in the optical system of a series of ground glass filters of varying densities which will reduce the peak and average values of the heat flux without changing the shape of the pulse curve.

It is the combination of these two controls which provides the flexibility previously mentioned. Simply slowing down or speeding up the rate of rotation of the shutter mechanism shortens or lengthens the time base of the exposure pulse; this corresponds to varying the *yield* of the simulated detonation—the larger the weapon, the longer the pulse. And changing the ground glass filter to a more dense one is equivalent to adding the additional absorption of thermal energy which would take place if the radiation were out in the open and had to travel through some hundreds of yards of additional atmosphere; this corresponds to varying the *distance of the target* from the simulated weapon detonation. In calibrating this source in the laboratory, the same instruments originally used to obtain the full scale radiation measurements at the atomic proving grounds are utilized, thus providing a direct measure of the validity of the simulation. By means of this device, valuable information concerning the heat flash damage and incendiary effects of nuclear detonations on various materials and surfaces is being obtained to an extent that would never have been feasible if all of the tests had to be made in the field. There is the added advantage that direct observation of these effects is possible in the laboratory. The device is equally valuable in connection with studies by the MD's and biologists of the severity of burns to be expected, of the fundamental nature of the damage produced in a burn, and in seeking improved methods of treatment.

Figure 14. Fallout intensity measurements at the Nevada Proving Grounds. The shielded scanning device overhanging the rear of the trailer transmits its information to recording instruments inside. The operator, in protective clothing, is taking bearings to check his location.

The foregoing has been included in some detail as a typical example of successful laboratory simulation of nuclear weapons effects, with a resultant ability

Figure 15. Preliminary tests of the "washdown" countermeasure on the cruiser *Worcester*.

to obtain much more needed data at less cost and in a shorter length of time than could ever be done out in the field. Other examples of equally successful laboratory simulation could be cited in connection with studies of the effects of irradiation by gamma rays and neutrons. However, not everything can be done in the laboratory—for example, the basic information concerning radioactive fallout patterns must necessarily all be obtained in the field (Figure 14). In this instance, the laboratory efforts are being directed towards improvement of theory and mathematical processes through which these patterns can be more accurately predicted, assuming that the essential meteorological data are available. Radiac instrument evaluations also must be performed partly in the field to insure the discovery of the types of "bugs" that do not always show up in the laboratory.

The development and proof-testing of the "washdown" countermeasure for shipboard radioactive contamination has involved some interesting field test experiences. This has been a joint NRDL—Bureau of Ships effort. Thus it also has provided a good opportunity for the development of closer acquaintance between personnel of the Laboratory and the parent agency. It has been mentioned previously that laboratory experiments originally carried out with small panels indicated the proposed washdown system was promising enough to warrant full-scale testing. These tests were started in 1951, first on the destroyer *Dortch* and later on the cruiser *Worcester* (Figure 15) and the aircraft carrier *Shangri La*. The purpose of this phase was to determine whether it was possible, by using salt water supplied by the ships' own pumps and fire mains and delivered through a number of fixed spray nozzles, to keep the entire exposed area of the decks and superstructures sufficiently wet to provide protection comparable with that which had been achieved on small panels in the laboratory. For these initial shipboard tests, the "radioactivity" was simulated partly by means of a washable red dye and partly by a harmless chemical, both of which were applied by means of fog nozzles. The ships' officers were manifestly unhappy about the red dye, but accepted it as one of the fortunes, or rather misfortunes, of war.

The results of these preliminary tests were encouraging as to the extent of coverage obtainable, but to assume that the performance of this device would be equally satisfactory when the contaminant was radioactive fallout from an actual nuclear detonation was still too much of an extrapolation. A great deal was at stake, considering the initial cost of a sufficient amount of the equipment for the entire fleet, the training effort involved and the possible even greater cost if it did not do the job when the chips were down.

Accordingly, plans were made for proof-testing with actual fallout during the 1954 thermo-nuclear tests in the Pacific (Operation Castle). For this purpose, two Liberty Ships were borrowed from mothball storage and fitted out so that after steam was raised and the engines warmed up, they could

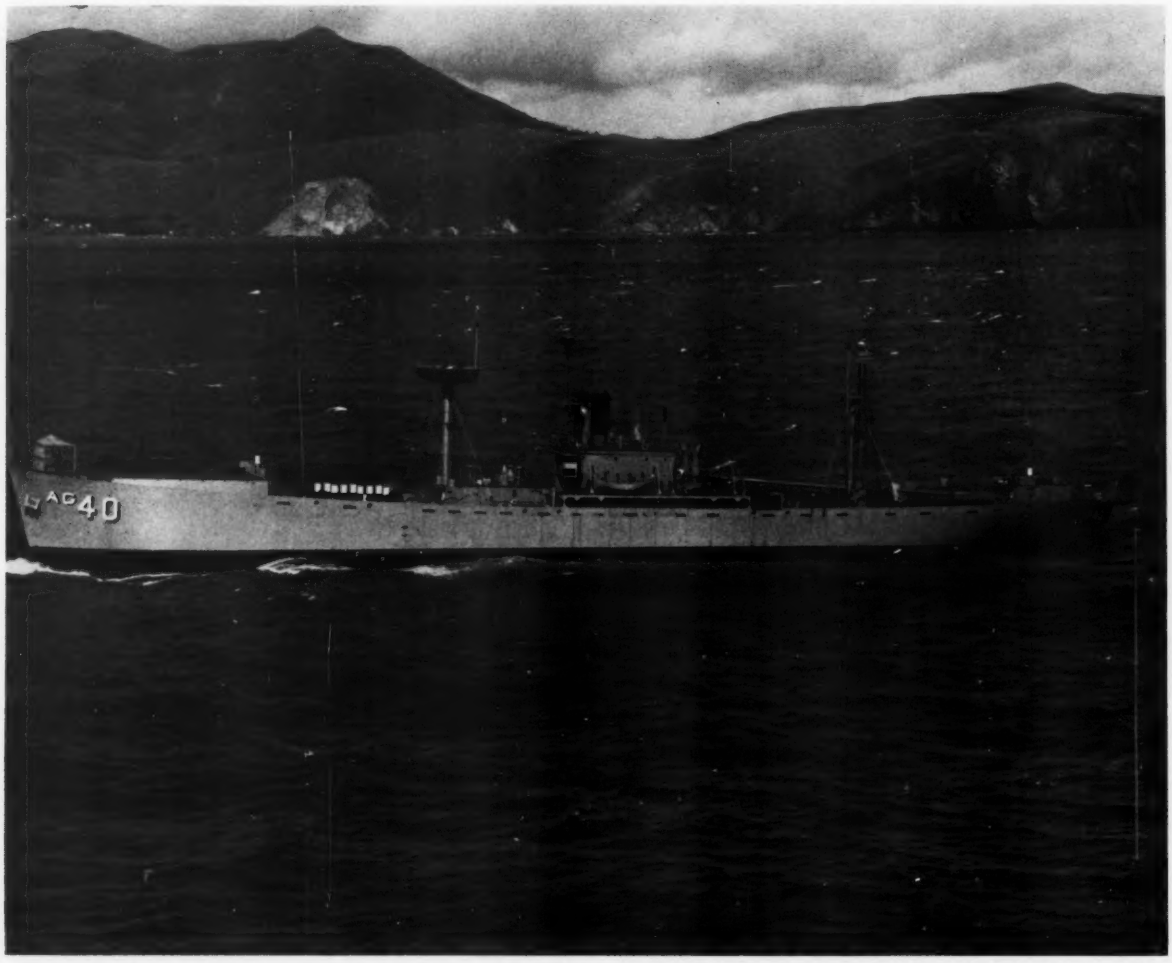


Figure 16. General view of YAG 40, a drone-operated field test vessel. The "bird bath" on the forward kingpost is a radioactive fallout collecting station.

be abandoned by their crews and operated by remote control. This included changes in course and speed, starting and stopping of the washdown system (in the case of the one ship so fitted), and eventual shutdown of the boilers and engines. The telemetered signals necessary to accomplish this could be transmitted either from an airplane, another surface ship, or a shielded location on board one of the two test ships.

After completion of fitting out and installation of special instruments and devices for detecting radiation and collecting and measuring fallout, the two ships were officially placed in service in time for the 1954 tests. For want of any better category they were designated as "YAG's" which is that used for miscellaneous naval auxiliaries. There can be no doubt about their being very "miscellaneous," as the Navy has never operated any other ships quite like them. In their later version (including modifications made after the 1954 tests for further use in 1956), it required only a glance to see that something unusual was in the air, as each had a tremendous bowl-shaped structure (called the "bird-bath") perched about sixty feet above the water on top of the forward king-post (Figure 16). This provided one of the primary stations for fallout sampling. In addition, the topsides were cluttered with large plastic cylinders with dome-shaped tops which looked like giant fungi sprouting in the wake of a tropical jungle rainstorm (Figure 17). These were shields for gamma radiation measuring instruments and each contained a cluster of several detectors pre-set for different intensities, since it could never be known in advance just what ranges would be encountered. Other topside instrumentation included a small dumb-waiter in the bow which automatically snatched a fallout sampling tray on signal from below. The dumb-waiter then took off with the tray, but not until it had carefully put out a fresh one for the next order.

The installations below decks were equally unconventional. One large concrete-and-lead shielded

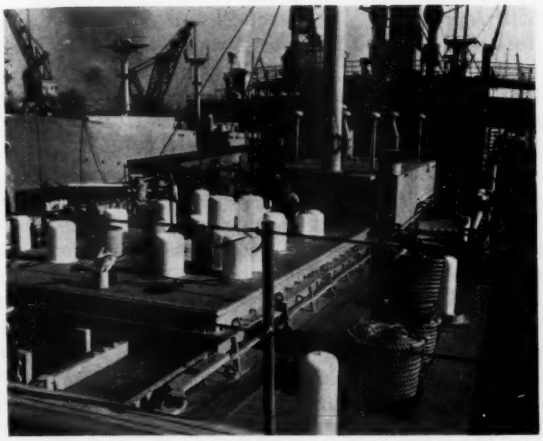


Figure 17. Gamma radiation detector stations on deck of a YAG. Ion chambers are mounted inside the cylindrical shields.

Figure 18. Shielded instrument compartment below-decks on a YAG. The panels shown receive and record the radiation intensity readings from the detectors shown in Figure 17.

room contained rows of instrument panels (Figure 18) in which the radiation intensities as detected at each of the topside stations and various points below decks were continuously recorded on moving strips of paper. This provided records which could later be correlated as to time. Another shielded laboratory room, at the lower end of the dumb-waiter, had facilities for immediate analysis of the radioactive samples. The key station was a central control room which provided an adequately shielded base for the operating and laboratory personnel when conditions topside, or even below decks in most other locations, were temporarily too "hot" for occupancy. In this case, in order to obtain sufficient protection with a minimum outlay for special construction, the shielding medium used was water. Ordinary water can be a very satisfactory shield against radioactivity provided there is a sufficient cross-section of it. This was obtained by constructing the control room in the form of a watertight tank suspended in one of the ship's cargo holds, with access through a single small vertical watertight trunk. Flooding the hold then provided an ample thickness of liquid shielding on all sides of the control room.

From this room, a closed television circuit provided a continuous view of the engine room gauge board and another was connected with a viewing camera on one of the masts. This latter camera could be rotated and elevated to scan in all directions. One purpose for which it was used was to observe the other YAG when the two were proceeding in company, so that both could be maneuvered from a single control room, using the telemetering circuits previously mentioned.

Altho operation of both of the YAG's as drone ships proved successful and was used on some occasions, the shielded control room arrangement was found to be so satisfactory that this became the primary method. In this manner, the YAG's have been maneuvered into fallout areas involving radiation intensities that would have been lethal to exposed personnel, but without exceeding the normal peacetime radiation dosage limits for the shielded participants. Valuable data have been obtained concerning the time and rate of arrival of fallout from nuclear weapons, and the additional goal of thor-

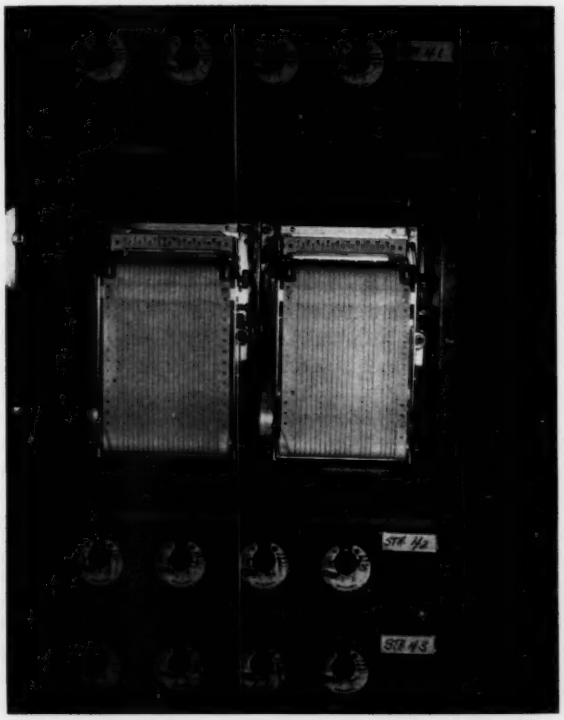


Figure 19. Close-up view of a gamma recorder station. A few preliminary horizontal-line "pips," signifying the arrival of radioactive fallout topside, can be seen in channels 17 to 19 on the left.

Figure 20. Full scale tests of decontamination methods at Camp Stoneman, California. This operation was carried out jointly by personnel of NRDL and the Army Chemical Corps in the fall of 1956.

oughly proof-testing the "washdown" countermeasure also was achieved.

In the fitting out of test ships such as those just described, the proximity of the Laboratory to the design, waterfront and shop facilities of the San Francisco and Mare Island Naval Shipyards has proved most fortunate. In return, shipyard personnel have gained some valuable experience in preparing for and dealing with radioactive contamination in ships and equipment.

Laboratory personnel witnessed still another proof-testing at the 1954 Pacific operation when, due to the unexpected shift in winds which caused the contamination of several inhabited atolls, a few of the ships of the Naval task force also found themselves caught in the fringes of the fallout pattern. Temporary "washdown" installations which had been put on board prior to the operation as a precautionary measure immediately were put into use, and kept the situation entirely under control. By coincidence, a number of the NRDL scientific and technical personnel were passengers on board these vessels at the time. They watched the satisfactory performance of the equipment with considerable personal interest, and also took advantage of the opportunity to obtain some data under operating conditions.

Large amounts of raw data seldom are of any use until they are boiled down to manageable concentrations, and unless this is anticipated in the planning stage, a field project can bog down from accumulation of too much undigested data. The gamma radiation measurements obtained on the YAG's might well have ended up in this muscle-bound state, as the continuous recording of radiation intensities from a number of different stations on each ship over periods of many hours resulted in an enormous quantity of records. However, considerable advance attention was given to this part of the problem. The detectors and circuits were so designed that the data were registered by the pen-and-ink recorders (Figure 19) in the form of a series of short horizontal lines or "pips" in which the spacing of the pips was a measure of the radiation intensity. Since this type of record is well adapted to electronic scanning, during the same period that the detection equipment was being developed and installed on the ships, an electronic device for automatically analyzing the records also was developed and constructed at the Laboratory. In this device small photo-cells scan each channel of the tapes as they are fed through at a fairly high speed, and the frequency is automatically plotted as a curve of radiation intensity or dose rate against time, while through electronic integration a second curve also is produced which is the time-integral of the first and thus represents the total radiation dosage.

The conception and development of field measurement and data analyzing systems of this kind require close teamwork between the physicist, electronic scientist, engineer and skilled instrument mechanics and technicians. The one described is an example of a number of systems and devices which have been produced at NRDL for obtaining radiation and fallout data on board ships, aircraft and on land stations. The results are used first to fill gaps in the knowledge of weapons effects and finally, by further integration and study of results from both laboratory and field work, to develop valid concepts for countermeasures.

A noteworthy full scale field test was conducted on land by NRDL in the fall of 1956 in collaboration with Army Chemical Corps Personnel. A portion of the Army's deactivated Camp Stoneman was used for test and evaluation of decontamination procedures for buildings and paved areas (Figure 20). For this purpose, both wet and dry types of synthetic "fallout" were used, the former being made from mud taken from San Francisco Bay. The radioactive tracer constituent chosen was one with a short half-life so that after it had served its purpose it would quickly decay to harmless levels.

In the foregoing there has been presented first a general summary and then some specific examples of some of the highlights of the NRDL research program, both in the laboratory and in the field. To summarize it very briefly, one might say that it all is directed towards the common goal of determining how nuclear radiation and radioactive contaminants are produced, what their characteristics are, how they reach possible targets and in what amount, what harm they are likely to do and what can be done about it.

This is a large task and it is not surprising, therefore, to find that in its efforts to fulfill it, NRDL has grown over a span of 10 years from the mere dozen ex-crossroads monitors to a staff of over 600. More than 300 of those on board are scientific or technical personnel, including some 50 at the Ph.D. or M.D. level who hold positions as supervisors, program leaders or consultants within the Scientific

Department. That department is headed by the Scientific Director, a civilian bio-chemist who, like several other senior members of the NRDL scientific staff, migrated west from the Oak Ridge National Laboratory. The Associate Scientific Director is a nuclear physicist whose earlier career included work and study at the Radiation Laboratory of the University of California. This complementary choice of backgrounds for the Scientific Director and his Associate is designed to help in bridging the unusually broad variety of scientific skills required for the accomplishment of the Laboratory's mission. The M.D.'s also are represented at the management level by a senior Naval medical research specialist who, in addition to heading the Laboratory's Medical Department has been serving as head of the Bio-Medical Division. The Nucleonics Division is headed by a physicist, Chemical Technology by a radiological chemist, and the Military Evaluations Group by an engineer whose basic training was in naval architecture. In addition to this last-mentioned key post, those members of the staff who are engineers have no reason to complain of any lack of representation at the management level, as the billet of Commanding Officer and Director at NRDL is one which has been designated for a senior Naval Engineering Duty officer.

The ratio of more than fifty per cent scientific, engineering and technical personnel to the Laboratory staff as a whole is considered to be a favorable one, especially in view of the heavy demands imposed by the nature of its work in such areas as physical security, fiscal control, and logistic support of field work. The groups which carry out these supporting staff and service functions are organized and distributed within the Technical-Administrative Services Department, the Medical Department, and the staff of the Commanding Officer and Director. The Technical-Administrative Services Department provides a variety of engineering and shop services including such specialized ones as instrument maintenance and glass-blowing; security and communications; technical information and library; logistic support; employee services and transportation. The Medical Department is responsible for radiological health and safety. In addition to uniformed medical personnel its staff includes the civilian health physicists whose monitoring and inspection functions are essential to the safety of all personnel working in an establishment which regularly utilizes and handles radioactive materials. The organization and functions of the Scientific Department have been described previously.

The three Department Heads report to the Commanding Officer and Director in both a line and staff capacity. Their contacts with him, which are frequent and informal, are more often as consultants in their staff capacities, since "management by exception" has long been an established principal at NRDL at the higher organizational levels and Department and Division Heads are encouraged to function autonomously within the general limits of basic policy. The Commanding Officer's staff also includes the groups concerned with comptrollership and management engineering, Naval and civilian personnel administration, and the Program Officers.

The status and functions of the Program Officers are believed to warrant some discussion. They are about ten in number and encompass a variety of military professional and technical backgrounds, such as naval architecture, aviation, electronics, military and civil engineering, and chemical warfare. All of the Armed Services are represented in this group, and in their liason capacity these officers are usually identified with some particular Service agency such as the Bureaus of Ships, Aeronautics and Yards and Docks of the Navy, the Offices of the Chief of Research and Development, Chief of the Chemical Corps and the Chief of Engineers of the Army, the Air Force Director of Research and Development, and the Armed Forces Special Weapons Project. The Program Officers carry out several different functions: they maintain close liason with their parent agencies which, collectively, represent by far the greater part of the Laboratory's technical and financial support. This liason is a two-way street—it not only serves to keep the sponsors continuously informed of progress and preliminary results of the laboratory or field work of interest to them, but also provides a ready channel by which the NRDL staff can obtain additional information or background data needed for its work.

The Program Officers also contribute their own professional knowledge and experience to the Laboratory's work when and as it may be needed. In the accomplishment of this, however, the cordial military-civilian professional relationship which has been developed over a period of some years at NRDL is carefully safeguarded by having the Program Officers act in a staff and advisory capacity, without upsetting the normal lines of supervision of the Scientific Department. On this point it is the author's firm conviction, based on observation at NRDL and elsewhere, that where a joint military-civilian effort is required in areas involving comparable levels of professional education and background, the only sound basis for the relationship between the civilian and uniformed professionals is one of mutual respect for and understanding of each party's ability and motivation. Unless this exists or can be developed, no amount of edicts or orders will ever be a satisfactory substitute for it.

As might be expected, the experience of the Program Officers is particularly valuable in connection with field tests, both in the planning stages and during the actual operations. It has not been unusual to find the services of one of these officers sought by several different laboratory groups for a forthcoming field operation. While this may cause him to feel harried at times, it also is very good for his morale.

During the growth of its program, staff and facilities, the organizational position and command status

of NRDL have undergone a corresponding evolution. From its embryonic state as a project attached to the Industrial Laboratory of the San Francisco Naval Shipyard, the "Naval Radiation Laboratory," as it was then called, soon grew to be a separate Shipyard Department. Eventually this status was found to be incompatible with the Laboratory's size and mission, and in 1950 NRDL was made a separate activity and designated as a component of the San Francisco Naval Base of the Twelfth Naval District. The Laboratory's management tie is with the Bureau of Ships and its technical control also is derived from that Bureau except that for medical research matters, technical guidance stems from the Bureau of Medicine and Surgery. The various other sponsoring agencies are, of course, fully consulted in the formulation of those portions of the laboratory program in which they have a joint interest.

In examining the Laboratory's history and present technical position, one aspect in particular stands out. Many of the distinguished scientists and research administrators, both from the U.S. and abroad who have had occasion to visit NRDL have commented that nowhere else in the world do they know of an establishment where a substantial number of top-level research people in *both* the physical and biological sciences are working together in a single, closely integrated department. This is reflected in the design of the new Laboratory building itself, where the medical and biological scientists are to be found on the fifth floor, the chemists near by on the sixth and the physicists and electronic scientists on the fourth. It is paying off in ways which go far beyond the obvious advantage to the M.D.'s and biologists of having physicists and chemists close at hand to take over or assist in delicate physical and radio-chemical tests, where extreme accuracy is essential for the detection of subtle effects which often seem to be the rule rather than the exception in this field. In return, the physicists, chemists and engineers profit by having continuous access to the only species of experts who can authoritatively aid them in interpreting the useability and significance of their findings in terms, for example, of whether an individual who has encountered a radiation situation will be able to continue to do his job for the next hour, week, month or year, and if so at what ultimate cost. A good example of an important area where continuous biological experimental support is especially helpful to the physicist is the case of neutron dosimetry. A physicist working in that field once was heard to remark that for reliable prediction of neutron effects, especially if a wide assortment of energies were involved, he had yet to see a "black box" as accurate as a biologist's mouse, although he hoped to produce one eventually.

Finally, the capability of assembling both medical and physical sciences research personnel around the same conference or laboratory work table on short notice is a tremendous asset, especially when the parties concerned have worked together for a long enough period to be able fully to understand their respective professional tongues. This type of joint effort takes place routinely at NRDL in the planning of each major new project or test, evaluation of results, preparation or review of a technical manual, and on many other appropriate occasions.

Although established by the Bureau of Ships and operated within the Department of the Navy, NRDL has an unusually broad cross-section of contacts with other Armed Service and governmental agencies. When the new Laboratory facility was approved at the Department of Defense level, one of the stipulations was that its services would continue to be made available to all components of the Armed Forces. The wording of its presently assigned mission also commits it to the broad task of development of radiological protective devices and procedures "for shipboard, aircraft, and land areas," and "preparation of data for training information required by the military services, including assistance to other federal agencies and government contractors . . . ."

The Bureau of Ships, as the founding and management activity, always has had an extensive research program at NRDL. Other Navy Department agencies which have utilized the Laboratory's services to a sufficient extent to result in the establishment and support of definite programs or projects include the Bureaus of Medicine and Surgery, Yards and Docks, Aeronautics, Supplies and Accounts, and the Office of Naval Research. Others have included several different agencies of the U.S. Army and the U.S. Air Force, the U.S. Marine Corps, Armed Forces Special Weapons Project, Atomic Energy Commission and the Federal Civil Defense Administration.

Where there is an interest in a particular project on the part of more than one agency, arrangements often have been made for joint sponsorship and support as, for example, by the Army Engineers and Navy Civil Engineers. Also, the Laboratory undertakes continuously to keep its program as a whole consolidated and integrated, so that where basic laboratory or field data are needed for several different projects, it is obtained on a shared basis and costs apportioned accordingly. This does not make life any easier for the NRDL fiscal staff, but it is favorable to overall progress and economy.

The extent to which the work at NRDL has brought together so many different scientific disciplines within its own staff, and so many different agencies as joint sponsors of its program, provides a convincing demonstration that the atom can bring things together as well as blow them apart, and that its "binding energy" can be effective at the human as well as the sub-nuclear level.

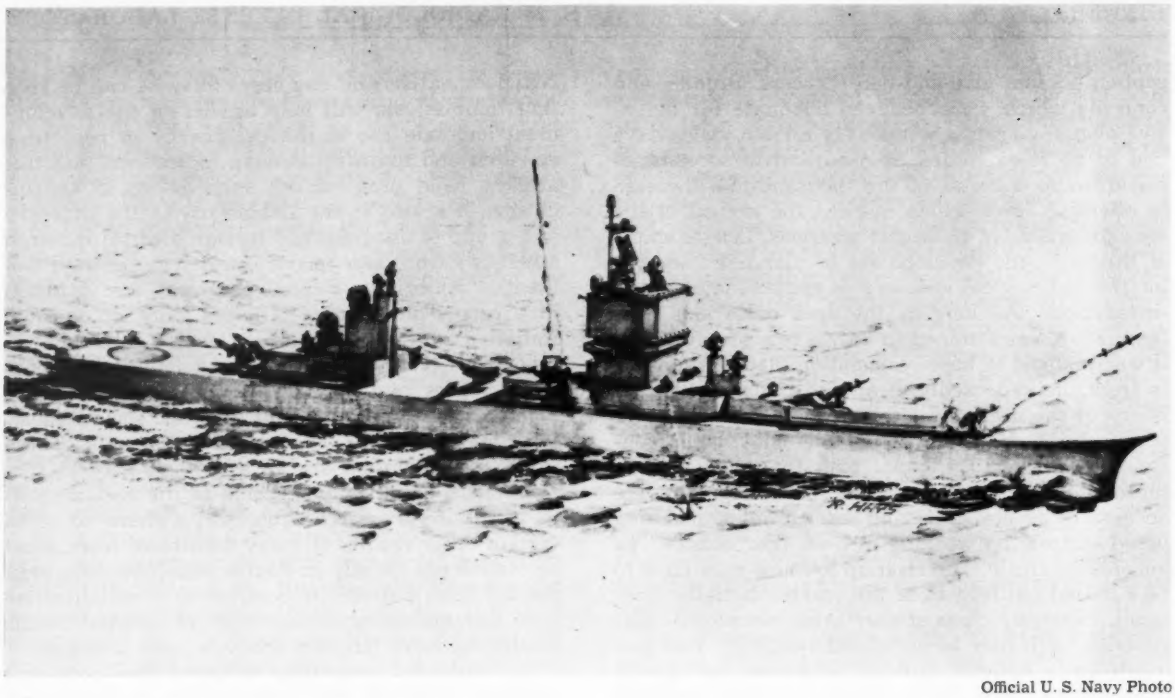
The history of warfare contains many examples of developmental battles between weapons and countermeasures, of which the prolonged contests of projectiles versus armor and torpedoes versus underwater protection systems are typical. NRDL personnel have found nuclear weapons to be no ex-

ception to this give-and-take process. Studies and concepts which were believed adequate for defensive planning against weapons of kiloton yields have had to be re-examined, revised and in some cases discarded as a result of the thousand-fold increase in offensive force which marked the arrival of the megaton yields of hydrogen weapons. One example of this is in the development of planning concepts for the radiological recovery of contaminated shore installations. As long as the area of serious contamination was confined to only a few square miles, it was realistic to base reclamation plans on moving in from the supposedly clean and undamaged periphery of the area and clearing it up by a series of penetrations. However, with the convincing confirmation at the 1954 Pacific tests that even a single thermo-nuclear weapon can seriously contaminate an area of several thousand square miles, planning based entirely on working in from the "outside" no longer is realistic. The cleanup job now may have to be handled entirely from the *inside*—initially from small, relatively clean shelter areas completely surrounded by higher levels of radio-activity. This is a much more difficult problem and requires careful conservation of radiation dosage through adequate shelter, proper timing and optimum use of previously developed decontamination procedures. Such situations *can* be handled if the essential advance planning has taken place. Studies made by NRDL are assisting in the re-evaluation of the civil as well as military defense problems created by this necessary change in planning assumptions.

The preceding discussion of NRDL's work has been based on its attack against the specific naval and military problems which are set forth in its mission and represented in its program. The present unfortunate division of the populations of the world into two camps—one free and one slave—with growing nuclear arsenals on both sides, is in itself sufficient to provide plenty of motivation for the efforts of the joint military and civilian staff at the Laboratory. However, its members also have another strong source of motivation in the knowledge that practically all of their work, in addition to its relation to present needs of the national defense, is of value in connection with peacetime applications of nuclear energy. As the Laboratory's Scientific Director, Dr. Paul Tompkins, has expressed it, man still has much to discover about "the fine art of living with the atom." Other military research agencies have made important contributions to peacetime advances in such fields as propulsion, metallurgy, communications and medicine. The NRDL scientists and engineers likewise can be sure that their efforts will help accelerate the development and safe use of nuclear energy in peacetime research and industry. Among indications that this already is in progress are such events as the inclusion of a visit to the Laboratory in the itinerary of a group of distinguished foreign medical research specialists who came to this country under the President's "Atoms for Peace" program; the inclusion of a report on some of NRDL's work on thermal radiation at the first international Conference on Solar Energy; and the numerous scientific and technical papers regularly accepted from NRDL staff members for presentation at scientific society meetings or publication in technical journals. These types of recognition are an essential factor in sustaining the vitality and morale of the civilian staff of a military research laboratory, where so often certain other results of many months of work must be mailed out quietly in double envelopes to a very limited distribution, in contrast to the launching and commissioning ceremonies of establishments producing more tangible products such as ships.

The potential peacetime value of the work and facilities of NRDL was particularly noted by the official visitors at the dedication of the new Laboratory in the fall of 1955. It was commented on by the principal speaker—Rear Admiral F. R. Furth, the chief of Naval Research—who concluded his remarks with a timely reminder of the peacetime contributions which often have been made by the Navy in the course of the diligent pursuit of its primary missions. On a separate occasion later that day another guest speaker, Dr. Luis Alvarez of the University of California Radiation Laboratory, recalled that Count Rumford's classic studies which led to the first real understanding of the nature of heat as a form of energy, resulted from observations which he made of the heat liberated in the boring of cannon at an arsenal.

The case of Count Rumford certainly is one of the outstanding examples of man's past success in deriving scientific benefits of major peacetime value from his very manufacture of weapons of destruction. It probably is related to his basic urge for survival. It is a fortunate ability, and one that can stand occasional nourishment in these times. It must have been an awareness of this which led the Chief of the Bureau of Ships, Rear Admiral A. G. Mumma to conclude the formal Ceremony of Dedication and embark the new Laboratory on its mission with these words: "... *I hereby dedicate this building to the service of the world.*"



Official U. S. Navy Photo

Official U. S. Navy Photo

Two views of an artist's conception of the Navy's first nuclear powered surface ship. This, the Guided Missile Cruiser *Long Beach* is scheduled in the fiscal year 1957, U. S. Navy shipbuilding program.

THE INFLUENCE OF WEAPONS ON MODERN STRATEGY

ACKNOWLEDGEMENT

Professor Gordon B. Turner, a Consultant for International Relations and Social Sciences at the Naval War College, Newport, R.I., delivered the following lecture at the College on 18 December 1956. From 1950 to 1952, Professor Turner was an instructor in History at Princeton University, serving as research assistant on an Organizational Behavior Project there during 1951-1952 and as Director of the Military History Project the following year. Since 1952, he has been Assistant Professor of History at Princeton University. Professor Turner is currently undertaking research on the History of American Military Policy under a Social Science Research Council grant and also teaching the History of Military Affairs in Western Society at Princeton University. He is the editor of A History of Military Affairs in Western Society Since the Eighteenth Century. *Professor Turner was on leave from the University of Princeton during the first term of the 1956-1957 academic year to act as Consultant for International Relations and Social Sciences at the Naval War College where he now occupies the Ernest J. King Chair of Maritime History.*

Gentlemen: My subject this morning is "The Influence of Weapons on Modern Strategy," with a minimum of discussion on historical perspectives and maximum coverage of developments in the decade just past and the decade next to come. This is a large and complex subject, so without preliminary remarks I shall plunge right in.

In discussing weapons of the period 1945 to 1965, the first thing we should be clear about is that we are not concerned solely with firepower but with mobility as well. Although the element of mass destructiveness is exercising a profound influence on strategic planning, equally impressive in its impact is the mobility of the new weapons complex, and by mobility I mean both range and speed. In this year, 1956, firepower has already reached a capacity for destructiveness which is at the point of diminishing returns, but we are just on the threshold of the absolute in speed and range. In the next decade or so, we can expect that nuclear propulsion will catch up with nuclear explosiveness to give us highly destructive weapons of infinite mobility.

In assessing the influence of modern weapons on strategy, then, we should, if we are to make that assessment meaningful, consider more than the bomb and the shell. We should include also the means by which the firepower is conveyed to the target. In this context not only the bomb, the rocket and the guided missile are weapons, but the nuclear-powered submarine, aircraft and aircraft carrier, and the supersonic plane should all be considered as weapons, as weapons systems, or, if you prefer, as a complex of weapons systems.

Weapons, looked at in these terms, have already had certain practical, tangible effects upon strategy itself. But more important they are having, and will continue to have, profound effects upon strategic theory, upon the whole process of thinking out just what war is and what strategy means in the nuclear age. What are these effects—both the practical and theoretical? There are six that I want to list briefly and then discuss in greater detail.

First, the present weapons complex, by making the offense vastly superior to the defense, has convinced us as a defense-minded nation that we must depend for protection on instant retaliation. Weapons of the future, however, will make this strategy obsolete unless we increase the mobility of our weapons sys-

tem. Second, modern weapons have thus far encouraged us to formulate strategy in terms of deterrence or defeat, all or nothing, peace or war, capitulation or suicide. This is unacceptable. Therefore, third, we are being forced to reshape our thinking about war itself in order to give us greater freedom of strategic maneuver.

Fourth, while these new weapons have in the last ten years made us think of strategy primarily as a science of destruction, in the future they are going to make us think of it once again as the art of control. Moreover, and this is the fifth point, under the impact of new weapons, military strategy will have to be restored to its proper place as only one element in national strategy, and a subordinate one at that. And, sixth, modern weapons are making necessary a renewed appreciation of the role of logistics in strategy—a role we have tended to forget or submerge in our fascination with nuclear power as a destructive force rather than as a means of propulsion.

Now, if we were to draw up a balance sheet on these six points and look at the net effect of the new weapons, some might conclude that strategy is being simplified—made a matter of black and white—whereas by all tenets of logic it should be realized that strategy is every day becoming more complex, less a science of measuring degrees of destruction and more the art of maneuvere and control. Perhaps we should say that brainpower or intellectual insight is the missing element in strategy today. I don't mean that able men are not struggling to reshape strategic thinking. They are. But the revolution effected by weapons has been so swift that it is difficult to keep pace with events.

Now, from such preliminary thinking as has been done, what can be said about the influence of weapons of offensive *vs.* defensive strategy? Historically, increases in firepower have generally favored the defensive. This was certainly the case in the First World War when artillery was lined up hub to hub, and human flesh could make no headway against it. On the other hand, advances in mobility have generally favored the offense. During World War II, when aircraft flew over the lines and tanks sliced through them, the offensive was rehabilitated even in the face of vastly increased firepower. In the postwar years it has been the mobility of long-range bombers with their nuclear payloads which have kept the offensive supreme.

Again historically, when the offense has outstripped the defense, the classical strategic solution has been to meet the aggressor with a counterthreat. This has naturally led us, with our capacities of firepower and mobility, to the doctrine of retaliation. This is what the modern weapons complex has done to strategy so far. But have we thought through the situation fully and given due weight to the weapons of the future?

I think not. Given our present strategic doctrine, the supersonic bomber and intercontinental missile of the future may hand the enemy the chance to destroy our retaliatory power before it is ever launched. With the degree of speed and accuracy forecast for weapons systems of the future, the defender's ability to defend himself may well decline to zero. Under such circumstances we would have to strike first or capitulate. These would be acts of desperation which we must avoid. The aggressor, by incurring the onus of the entire world, would lose the peace by the very process he employed in winning the war.

What can we do about this? There can be only one answer unless all nuclear powers reach such a harmonious relationship and mutual trust as to permit disarmament. Our only alternative is to give our weapons complex such mobility as to guarantee us the power to retaliate under any circumstances. Our current strategy depends upon a large number of fixed air bases spread throughout the free world. This will not be adequate for the future. When supersonic speeds become a commonplace among the great powers of the world, and when intercontinental ballastic missiles with nuclear warheads are capable of being laid on targets in advance, our fixed bases will scarcely remain retaliatory assets. They will be easy to locate, difficult to defend and vulnerable to a single hit.

Nuclear-powered aircraft carriers of the future, constantly on the move, will increase the mobility of our weapons complex to some extent, and if long range aircraft and missiles can be launched from them, we will retain some retaliatory capability. Nevertheless, for the years ahead they will not be enough. They will be relatively slow-moving and will make tempting targets for manned aircraft.

It is in the development of the nuclear-powered seaplane that we may well find the best answer to this problem of mobility. I say seaplane rather than land-based aircraft for two reasons. In the first place, land-based planes, even if they could remain in the air to the limit of human endurance, would have to return eventually to a fixed base which could be obliterated. For maximum assurance that a surprise attack will not destroy our retaliatory power, moving bases are essential. Counterattacking forces must not only be widely dispersed but constantly shifting.

In the second place, I am informed that the flying boat is at present the only answer to the weight problem of nuclear power plants. No landing gear has yet been designed which can stand such a burden except for the seaplane hull. It would take relatively few such aircraft, constantly on the move with their own transportable pontoon docks, establishing bases for themselves wherever a suitable stretch of water was available, to keep our retaliatory power high. Such docks have been developed. When the nuclear-powered seaplane has also been constructed (and research on it is already under way), a few of them can give a measure of guaranteed retaliatory power unmatched by dozens of vulnerable land-based craft.

Fortunately some people are already thinking about how to fit such seaplanes into our retaliation

system as they become available. They realize that the firepower of the present, and the mobility which the future seems to offer, indicate that the counter-attack, or defense through offensive retaliation, will remain strategically valid only if we are not hypnotized by the pseudo-mobility of a completely land-based air force.

It has been truly said that strategy is indivisible. We must remember this, and think of strategy as a whole rather than let ourselves be ensnared by the lure of its separate elements. Under an integrated system of strategic thought we will concern ourselves less with a particular weapons system and whether it is land-based or sea-borne or is an aspect of air-power. We will concern ourselves instead with what strategy must accomplish, and then develop whatever weapons complex that strategy dictates.

My second point follows logically from the first. The construction of weapons which will guarantee our ability to retaliate is just a first step—not the last—for even if the enemy is deterred from launching an all-out attack through fear of committing suicide, there are other ways of waging war which we must be able to counter. Moreover, the enemy may not be deterred. By restricting ourselves to a retaliatory strategy, we are wagering our physical plant, our governmental structure and indeed our whole way of life against the enemy's. These are, to put it mildly, unfavorable odds. Military men should know better, and most of them do. They know that to risk their fleets and armies unnecessarily is an unforgivable error, and they will seek to accomplish their missions by means which will reduce the hazard. How much greater a blunder would it be for a nation to risk its existence by deliberately depending on a strategy which permits it no alternative but annihilation or capitulation in the face of every threat!

This nation has the highest standard of living in the world; it has a democratic philosophy and system of government which is the greatest tribute to man's ingenuity ever devised. To throw these assets on the bargaining table as equal stakes against the poverty and human degradation of the Soviet system is an act that cannot be tolerated unless our vital interests are imperiled. And the fact is that they will not be risked if the Soviets act only in areas where our interests are of minor import. The principle of deterrence is, after all, based on the will to act. If we are unwilling to set our rigid strategy in motion except where our vital interests are threatened, we will lose our minor assets by default. And it is worth noting that a series of minor losses can have important cumulative effects and may even culminate in a vital loss to the free world.

It has been said that our strategic air force is an insurance policy protecting us from nuclear weapons in the hands of others. It has been called a police force to promote world stability. Both terms are semantically incorrect. SAC does not *insure* us against assault nor does it pay off if we are attacked. It is a desperation strategy pure and simple. As for a police force, *its* purpose is to keep order by preventing crime and apprehending criminals. Strategic air power cannot possibly play all these roles. It can perhaps prevent major crimes and punish *them*, but chaos, not world order, will result from nuclear war. Strategic bombing is a method of employing weapons in one particular type of war. The very existence of SAC may channel future wars into something less than total conflicts, and *this* is its great asset. But we should not claim for it more than it can do, and thus rigidify our strategy. We must still have the weapons and the strategy to cope with the lesser and more subtle conflicts that may arise.

How did we arrive at this all-or-nothing thinking? From the moment the first atomic bomb was dropped on Japan we became hypnotized with the power we had created. Having a monopoly of this power we became complacent. Even when the threat from Russia became apparent, we had only a momentary twinge of uneasiness. Korea demonstrated that our nuclear strategy was impractical, and we were forced to build up our conventional forces in the Far East and in Europe. But this didn't last. Gradually we dropped back to the sterile concept that all but the most powerful weapons were futile. Almost daily we read in the papers and military journals that the eventual use of atomic weapons in war is inevitable. Military leaders, government officials and news analysts are saying either in criticism or with confidence: "A major war must now be atomic in nature. Why? Because the posture for atomic warfare cannot be reconciled with retaining a conventional capability." They are saying in other words that since we have nuclear weapons, we must use them, because they impose on us a nuclear strategy which leaves us no alternative.

Korea, Indo-China, Malaya, Suez and Algeria are vivid demonstrations that a strategy of all or nothing, of peace or total war, is unnecessary, unimaginative and inappropriate to the nuclear age. But so blinded are some of us by our new weapons and their influence on strategy that we cannot see what is staring us in the face. Even today when we have lost our monopoly of nuclear power, we cling to our faith in a strategy which had only limited validity when we alone held that power. Being dazzled by our nuclear weapons, we are basing our strategy on what these weapons and no others can permit us to do. Nuclear weapons, then, have become an end in themselves rather than one of many means to attain political ends.

By premising our thinking on weapons of mass destruction, and basing our military strategy almost exclusively on the advantages of these weapons, we have deprived ourselves of flexibility. With a rigid military strategy, no policies can be formulated and no objectives can be achieved which cannot be implemented by nuclear destruction. It is one thing to negotiate through strength; it is quite another to negotiate on the basis of a power which breeds self-destruction. We are not only power-minded but nu-

clear power-minded. Our rigid strategy did not help us in Korea. It has given us only limited additional strength to deal with the Suez situation and none for the Hungarian crisis. In a sense it ties our hands by tying our minds to a single objective: total peace or total war—deterrence or self destruction.

This is what the development of nuclear weapons has done to strategy to date. It has rigidified it and left us increasingly with no policy but deter or die. Such a situation is obviously unacceptable. Thus we are forced to reshape our thinking not only about strategy but first of all about war itself. We must find ways to give us greater freedom of maneuver by providing more alternative objectives. There is nothing inherent in the weapons system, in strategy, or policy, or in the international situation which automatically restricts us to the extreme alternatives of peace or total war. Nothing limits us but our range of thinking.

The idea that wars *must* reach the apex of destructiveness to be successful is not a new one. It began with a misinterpretation of Clausewitz; it grew in stature during the First and Second World Wars; and it has become a fetish with us since the growth of nuclear weapons. There is nothing in this concept, however, that can't be changed by changing our thought processes. You know the expression: "There's nothing right or wrong but thinking makes it so." This is the case here. If *our* statesmen and soldiers and those of the enemy are convinced that total war is inevitable, it will be. They will make it so by adopting strategic plans which permit no alternative.

Had there been no Korean conflict, the idea that war must be total might have proved impossible to shake. But we *have* had a limited war waged by a nation possessing atomic power, and more recently we've had one in the Middle East. These two cases alone provide ample demonstration that, even with nuclear weapons, wars do not have to be carried to the extreme. They can be, they may be, but they do not have to be.

If we are going to minimize the chance of nuclear war, we must provide alternatives. To do this we must start our thinking not with war as an end in itself but with the purposes of war or the objectives which they serve. Now, war as a rational act must serve to maintain or strengthen national security. Nuclear war can be employed only as a last resort, because the most it can do is to preserve the sovereignty of the victor. It will virtually destroy everything else. Certainly, nuclear war cannot leave a belligerent better off than before the war; it can only leave it better off than the enemy. The meaning of the phrase "to win a war" has, then, been sharply curtailed. The more limited the war, the more advantages victory can bring. The winner of a limited war can win in every sense of the term; the victor of a total war cannot.

With this in mind we can think through our problem more clearly. We will not fall into the line of thought which once caused a German General to say: "The best thing that diplomacy can do is to create the most favorable situation for military action." To be sure this is one objective of diplomacy—to build alliances and create situations of strength, but the primary objective of both diplomacy and war is to create the most favorable situation for a stable peace. Our foreign policy must see to it that we do not become isolated in an inflamed world, for this would create conditions for total war. Likewise, our strategic plans must be so framed that there is something other than wreckage to work with when peace is restored.

What I am driving at is this. We must get away from the idea that policy governs only until war begins, that it is then discarded and war emerges as an end in itself. To prevent such an idea from dominating our minds, the first thing to do, is to stop thinking in terms of complete peace and stability, on the one hand, and uncontrolled and unlimited war on the other. At a time when weapons have such a strong influence on strategy and when the single act of target selection can destroy the world or prevent postwar stability, it is dangerous for the policy-maker and the strategist to think in terms of extreme alternatives, although the tactical commander may have to do so.

It is time to realize that there is a yawning gap in our thinking between peace and unlimited war, that there are middle degrees of conflict, and that we can control our destinies only by keeping a firm hand on these lesser conflicts. We should be prepared to deal with realities and normalities rather than abstractions and extremes. Complete peace and absolute war have never existed. Total absence of conflict and war to the point of suicide are meaningless abstractions. Human nature being what it is, with its appetites, jealousies and passions, will never allow complete harmony to prevail. And if we can credit mankind with any degree of logic and intelligence at all, we can conclude that world suicide is an unlikely choice. It is the middle degrees of conflict between these extremes that should concern us, because these are the real areas in which we have to operate.

The actual situation reveals a continuum of conflict, starting with a maximum of harmony at one end and graduating toward increasingly intensive and broadening conflicts across the spectrum. We might describe these degrees of conflict in this way. First, there is the state of international tension at a level which still permits cooperation. Conflicts in this range may be economic or political in nature. They can have to do with trade barriers or boundary disputes. They may be local, regional or global in scope. This is a state of affairs in which we still have control of our actions and emotions. We are still using logic and reason to arrest conflict or wipe out its cause. This, historically, is the most normal state of international affairs—controlled conflict characterized by varying degrees of cooperation, compromise and the will to reduce tensions.

The next state of conflict is one that we have come to call "cold war," but which any previous

age would have characterized in quite different terms. We call it cold war because two great power blocs exist so violently opposed to one another that, but for the presence of nuclear weapons, they would long ago have been engaged in direct military action. The name we give to it is unimportant so long as we understand that it is a situation of conflict so acute and brittle that we have kept it controlled with only limited success. We might call it semi-controlled conflict, for, despite an arms race and threats of retaliation, brushfires occasionally do break out. Persuasion and pressure rather than cooperation characterize this conflict stage—mainly diplomatic persuasion and economic pressure, but with frequent threat of military force.

The last stage in which some degree of control is exercised is that called "limited war." Coercion rather than persuasion dominates this phase. It is one in which the final vestige of control is easily lost. One false move, one heightening of objectives, one wrong weapon employed, and the war of extinction can come with startling speed. Coercion gives way to destruction, and even if the world survives, the chance for a stable international order has been shattered. In limited warfare, however, there is still the possibility of restoring control, and there is everything to gain by doing so. This stage is man's last hope of survival.

Our efforts, then, and this includes our strategic thinking, should be maximized in the direction of keeping affairs at the lower end of the conflict spectrum. As long as we limit the intensity of conflict, we control our destinies; and strategy should be planned with this in mind. It is a fundamental error, and a dangerous one, to base strategic planning exclusively on that extreme state of affairs in which control has already been lost and destruction is inevitable.

Strategy, therefore, should not be considered as a science of destruction. Following the reasoning of Dr. Herbert Rosinski, I prefer to think of it as the art of control. This, you may recall, was the fourth point I made about the effect of modern weapons. Nuclear weapons have led us to think of strategy in terms of mathematics—so many miles of range per gallon of fuel, so much speed per unit of energy, so much destruction per target selected and pound of explosive dropped, so much mechanical efficiency per dollar spent. The machine replaces the man; the manned aircraft gives way to the guided missile. There is less thought about maneuver, flanking movements, double envelopments and more about the straight punch.

Strategy has reached a low point indeed when it depends on machines to destroy rather than on men to maneuver and control. It cannot fulfill its true function under such circumstances. After all, gentlemen, what is strategy but the manipulation of resources to achieve desired ends in situations of conflict? The element of conflict or competition is part and parcel of any strategic situation. We can't think of strategy divorced from a state of conflict. This is why we talk about strategy in poker, in football, in politics. In such cases we try to outwit, outplay, outmaneuver the opponent. We play for victory if we have the resources, the power, the cards, or whatever, but if we cannot win, we adjust our strategy to limit our losses. We figure odds, take risks, attempt to exercise control over the action of our opponent by bottling up his resources, by hobbling his stength, by depriving him of initiative. We don't try to destroy him, but deprive him of the ability or will to continue the play by destroying or curtailing his *resources.*

And so it is with the kind of strategy we are concerned with this morning—the strategy of a nation seeking to maintain its security in a world of conflict. By means of strategy the nation seeks three kinds of control. It seeks to direct or control its own resources, tools, weapons and power. It seeks to control or restrict the use of its enemy's resources by destroying them or making it unprofitable to use them. And it seeks to control the conflict situation—to channel it into lines most profitable to itself. Never before in history has the element of control been so important. Nuclear weapons have made it imperative that we keep the conflict in the lower ranges of intensity. The objective of strategy, whether national or military, is so to control its own power and that of the enemy that the conflict will not get out of hand and erupt into total war.

How is this to be done? One way is to always keep our eye on the objective, to realize that this objective is to maintain our way of life, and that the only way to do this is to control the conflict between our enemy and ourselves. We have already made a large stride in this direction when we have recognized that we are not in an all-or-nothing situation, but that the degrees of conflict are multiple and ever-shifting.

How does this help? Because to exercise control, we must have alternatives—alternative courses of action, alternative means, alternative goals. If our goal is total victory and our tools are hydrogen bombs, there's no alternative but total war. If, on the other hand, we set forth as our goal, keeping somewhere on the wide spectrum of conflict other than its extreme destructive end, we immediately give ourselves maneuver room. Our courses of action then lie in the economic, diplomatic, and psychological realms with all the tools available to those fields of action. Moreover, we have a wide range of alternatives in the military field ranging from simple displays of power to limited, peripheral wars. And, in all these cases, a good military strategy retains a tremendous ability to maneuver and capacity to keep the conflict under control.

The hydrogen bomb by giving us the power to commit suicide, has forced us to control this power, and has thus reopened for the military strategist vast new challenges for weapons development, and unparalleled opportunities to exercise imagination

in their employment. This should be an exciting and challenging age for the strategist. Never has he had a greater variety of tools in the field of communication, transportation and weaponry. Never has his theater of operations been larger, yet more accessible. Never has he been more capable of acting in the air, on the ground and in the sea. It's the weapons of mass destruction which have forced this opportunity on him, because never before has he had an enemy which can destroy his country in a matter of hours if he makes a simple mistake. His mental energies, then, must be directed as much toward controlling the enemy's actions as his own. This has always been true in war, but never to the extent it is today. Strategy, as the art of control, has come into its own once again.

Strategy, of course, is not simply a matter of *using* resources. It must also direct their development and timely construction. Let's take a current example. Last summer Britain and France envisaged military action in Suez, but neither country was ready to apply military power of a type suited to the situation. Both could have used strategic airpower immediately, but this couldn't accomplish the objective of physically occupying the canal and keeping it open. What was needed was a combination of sea and airborne landings supported by all the paraphernalia of conventional warfare. Neither France nor Britain had the weapons, forces or logistic capacity for such a rapid operation last summer, and apparently they didn't have it last month when they tried to seize the whole canal before it could be blocked. Their strategy was rendered useless and dangerous through lack of timely development of the means required to make it work.

The first thing then, the strategist must know, is the kinds of results he will be expected to achieve. Knowing this, he can then, and only then, determine the weapons and forces he will need. If he is to fight the kind of war which will create future conditions of peace, if he is to maintain the flexibility necessary to meet the wide range of conflicts which our continuum has revealed, he will need a wide range of weapons. If he is to be ready to fight instantly in any portion of the globe, under all conditions of weather and terrain, he must stockpile military hardware of quality and in quantity. If he is to strengthen the hand of the negotiators in cold war situations, he must have the capacity of graduated deterrence, for if we can only react massively and not oppose lesser aggressions against minor interests, the hands of the diplomat will be tied. In other words, the strategist must maintain the capacity of employing selective force as well as massive retaliation, and both must be ready for instant use.

Not only does the strategist need to deter all kinds of aggression, and keep the conflict limited, but he must have the means to make the enemy change his mind. His task in the nuclear age is to destroy the enemy's *will* to continue fighting rather than his ability to fight. For in order to destroy his ability completely, his cities or his military forces must be destroyed; and with Russia as the enemy, it appears that this can be done only by nuclear war. If, on the other hand, you can destroy the enemy's *will* to fight, you won't have to destroy his ability, and yours as well.

The means of curtailing an enemy's will to fight are numerous. The threat of massive retaliation is one important way. The ability to stop his minor aggressions in their tracks with precision weapons is another. Diplomacy and propaganda, and economic pressures, are still others, but these must be accompanied by military preparations which complement them rather than oppose them. As Clausewitz said over a century ago, there are a thousand ways to achieve objectives in war—some subtle and some not so subtle. The main thing to remember today is that the use of nuclear weapons, and especially strategic ones, reduces the thousand ways almost to one. As soon as military *destruction* is substituted for lesser forms of coercion and pressure, the ability to control the degree of conflict is lost, and so is our objective. In order to retain control—that is, to keep the war limited—the strategist must have the capacity to fight both general wars and local ones; he must have ground, sea and air weapons of infinite variety in order to protect his homeland and that of his allies.

Having developed the weapons needed to keep the conflict limited, the next step is to direct the *employment* of the weapons in accord with the situation. Weapons themselves are inert until put to use. It is one of the tasks of strategy to employ them correctly. Strategy, then, among other things, provides the intelligent direction of weapons and forces to the achievement of a variety of goals. Again, I emphasize the element of control, for strategy is an intelligent system of direction *and control*—a means of convincing the enemy that it is in his interest to sue for peace. Of course we must first convince ourselves that the absolute destructiveness of total war is the negation of strategy rather than the furtherance of policy.

And this leads me to my fifth point—that it is particularly important in the age of nuclear weapons for military strategy to be subordinate to national strategy. I touched on this a moment ago when I said there were certain non-military means which might persuade an enemy to stop fighting, and that military action should not contradict them. As you all know, in theory, military strategy has always been subordinate to national strategy, but the awfulness of modern weapons has made it particularly important that from now on we actually do keep military strategy in its proper place.

Please take particular note that I did not say military "men" but military "strategy" should play a subordinate role in national strategy. Paradoxically, it may be that in order to restrict the one it will be necessary to elevate the other. For in actuality it is

the civilian who is forcing preoccupation with weapons by failing to provide alternate objectives and policies, and by withholding the financial resources necessary to permit a flexible military strategy. I have every confidence that the military expert, if given a wide range of goals and ample means, would formulate alternate strategies. It is primarily because his strategy is rigid that it has come to dominate affairs.

Now, if we define national strategy as the art of developing and directing a nation's resources to the maintenance of national security, then military strategy must be the art of developing and directing *military* resources to the same end. You will note I do *not* say that the armed forces are to be used to achieve *military* aims, because this is not always the case. No matter what the resources—whether diplomatic or economic, psychological or military—they should be directed toward the maintenance of *national* security, national aims—not simply military ones. Here is where we often make our great mistakes. By directing military force exclusively toward military ends, we let military strategy override national strategy, and with today's weapons such a course can be a fatal one.

For example, some years ago we decided that one means of maintaining our national security was to strengthen Western Europe. We wanted to build it up as an element of strength for the free world. To that end we developed a national strategy which included employing our economic resources in giving economic aid to Europe. At that time our military strategy was based simply on attacking Russian cities from the air if the Soviet forces moved westward. Then under fear of Soviet military aggression we began giving military as well as economic aid to Western Europe. We entered into diplomatic negotiations to form an Atlantic Alliance in which we pledged ourselves actually to defend Western Europe. This was something new. The North Atlantic Pact was not designed to have us withdraw from Europe and return, but to defend it. When we had a monopoly of atomic weapons, our military strategy was in line with our national aim of keeping Europe whole. The economic, the diplomatic and the military elements of our national strategy were parallel.

But on the day that Russia exploded her first atomic bomb, the situation changed drastically. Since that time a military strategy based on using nuclear weapons has been out of harmony with our national aim of defending Europe. A nuclear war cannot preserve Europe; it can only insure its destruction and waste the economic resources we have poured into it. If we do not use the nuclear strategy we have devised, we must, in the absence of other means, withdraw from Europe, which, again, is contrary to our aims. If our military strategy can only produce destruction or withdrawal, it is dictating a national strategy of destruction or withdrawal whether we plan it so or not. The only way the two strategies can be brought into line with policy, is to provide weapons which will give us command of the air in order to keep Russian bombers out of Europe and lend cover to NATO forces on the ground. Tactical air power, however, remains secondary in our military scheme of things.

Putting this another way, we have one policy for peace: economic and military aid to strengthen Europe with massive retaliation to preserve the peace. And we have another policy for war: destruction or withdrawal. Our military strategy then is designed to achieve a military aim: military victory over Russia through destroying her even at the cost of wrecking Europe. Perhaps I have overdrawn the situation for the sake of brevity, but I think not. Certainly the essence of what I am saying is true; and it does not make sense. The only thing that does make sense is to make our military, economic and political strategies parallel so that they do not work at cross purposes. Only in this way can military strategy be a true servant of national policy. Our military plan in Western Europe should aim first at deterring war, and, failing this, to prosecute that war in such a way that we can achieve a favorable settlement with a minimum of damage to a healthy Europe. We must not let our preoccupation with mass destruction weapons make us frame a military strategy out of harmony with our ultimate objectives and out of harmony with the national strategy by which those objectives are to be pursued.

Now, I said a moment ago that I might be oversimplifying our current military strategy by implying that it was an all-or-nothing concept, but I wonder if I was. We *do* have air, sea and ground forces. We have some atomic weapons of relative precision as opposed to those of mass destruction, and we still retain a certain capability in conventional warfare. But the question is: how quickly can we put such forces into action and sustain them? Are we prepared logistically to shift from SAC and total war to infantry and brushfire conflicts? Has our strategic planning for unlimited war precluded us from exercising the control necessary to keep the current conflict limited? The answers to these questions necessarily turn on our logistic capabilities, for our armed forces as instruments of control, are of no use unless they can be transported to the point of conflict quickly and sustained long enough to permit them to stamp out brushfires and regain control.

You will recall that my sixth point concerning the influence of modern weapons was that they were causing us to subordinate the role of logistics in strategy. Gentlemen, this *is* the trend, and we must reverse it as a brief look at the definition of strategy will demonstrate. Strategy is the art of the possible—the logistically possible. It is, as I have said, the art of directing a nation's resources for the maintenance of national security. It is inseparable from logistics because both logistics and strategy

are concerned with resources. One provides them, the other employs them; and strategy can do no more than logistics permits. At the highest level of military decision it is frequently discovered, when it is too late, that a nation's strategy is restricted to what is logistically feasible rather than to what is strategically desired.

American strategy today is designed primarily to deter or destroy, and the main instrument to effect this is the Strategic Air Command. SAC rightly has priority on our military air transport system. Even if SAC is not used, ample air transportation must be held in reserve for it. The question is, whether under these conditions, M. A. T. S. is set up to implement any other strategy—especially one designed to control the enemy's actions by conventional means? Our strategic plans are apparently based on the full use of our air transportation, but what happens if an unforeseen emergency should arise?

Let's take an example which is only partly hypothetical. A few weeks ago we urged the creation of a United Nations Emergency Force to control the conflict in the Middle East. It was to our interest to keep the Suez open, and the government's policy was to get French, British and Israeli forces out of Egypt quickly so that Russian volunteers would have no excuse to move in. Our objective was to control the situation, to get the conflict back on a non-military basis, and to keep out alien military forces which might bring on a conflict of greater intensity. Air transportation was the quickest method of putting the UN Emergency Force on the scene, and we offered air transports on a limited scale to fly it to a staging area short of Egypt.

So much for the facts. The question is: could we have offered more planes without undue risk? SAC retained priority on our transport system and always will, because we can't afford to curtail in any way the effectiveness of our greatest deterrent and striking arm. The rest of M. A. T. S. has heavy commitments to other tasks; the evacuation of thousands of military dependents from danger zones, support of NATO, protection of the United States, and so forth. Moreover, what if Russian volunteers should begin moving in? Do we then drop bombs on Moscow and bring on the very war we are trying to avoid, or do we fly troops of our own into the Middle East either to limit the conflict geographically or perhaps prevent war altogether by facing the Russian volunteers with a superior force? The answer to this question depends upon our logistic capabilities.

Here is a situation in which we cannot exercise the control necessary to keep the conflict in reasonable bounds, because weapons of mass destruction have influenced our strategy in a single direction and caused us to underestimate the logistic capabilities necessary for a flexible strategy. And what has been said of air transport applies in varying degrees to every other aspect of logistics. I would also say, to the extent that the science of logistics is concerned with the movement of men, equipment and supplies, we should be making great efforts to see what nuclear propulsion can do for the development of that science.

Time does not permit me to give a full summary of the influence of weapons on strategy today and tomorrow, but this much should be said. Since nuclear power has made the offensive so vastly superior to the defensive, we must have a highly mobile weapons complex in order to retain our retaliatory capabilities. Keeping pace with this requirement is going to demand an integrated system of strategic thought in our military establishment, less concern with the separate components of air power, sea power and ground forces, and far greater emphasis on the logistic problems which a highly mobile weapons complex is bound to raise.

The new weapons of mass destruction have inflicted us with a kind of myopia. We have become so shortsighted as to plan our strategy in terms of an all-or-nothing policy when in fact, more than ever before, we should be concentrating on the middle ranges of conflict and framing our strategies, both national and military, with a view to controlling the situation in order to prevent it from degenerating into all-out war. Control requires flexibility. It requires an assortment of aims, of means and courses of action.

The strategist in the nuclear age, then, has a staggering task. He must first of all frame his plans so that they will be consistent with a wide range of national strategies all aimed at achieving our objective of maintaining our way of life. For this task, he must provide himself, in advance, with a variety of tools, and by this I mean, men and machines, communication and logistic techniques, and, above all, brainpower and imagination. With such instruments at his command, he will have the opportunity to restore strategy to its proper level, to lift it from the depths of mass destruction to the higher plane of persuasion, pressure and control. The strategist's challenge is to provide that intelligent direction which is the essence of strategy and which alone can save civilization. It is a superb opportunity. Let us not lose it.

SUSTAINING AN AIR-ATOMIC NAVY

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In an age of mortal danger we mortal men are concerned first of all with the safety of our own lives. And so we arm. By arming we seek to protect our homes, our families, our nation, civilization itself. With arms we try to build strength and confidence in the place of weakness and fear.

Yet the stronger we become the more we inspire fear and envy in the hearts of foreign rivals. The enemy that aroused us to action is himself aroused. The deeper the fear, the more powerful the arms, the greater the danger. The greater the danger, the deeper the fear, the more powerful the arms. This is the maelstrom of terror at the center of the struggle for world power.

Ours, however, is not only an age of mortal danger. It is also an era of volcanic change. Whole continents are trying to accomplish in decades things that men in Europe took centuries to achieve. The result is a tidal wave of social turmoil which, because of modern technology, cannot fail to have profound economic and political effects throughout the world. A Navy lieutenant in Seattle is ordered to reactivate a fleet tanker in San Diego because a lieutenant colonel in Cairo wanted Suez Canal revenues to build a dam at Aswan. U. S. military planes and Swiss Air transports fly United Nations troops to Egypt from Bogota, Copenhagen, and Oslo. An electronic miracle brings the blood of Budapest into the living rooms of Milwaukee and Houston. A transport miracle brings thousands of Hungarian survivors to countless American communities.

The world is insecure and the future uncertain. So we must arm. We arm ourselves and our friends. We sign mutual security pacts with 42 other nations to thwart the one thing we most fear: Sino-Soviet expansion.

Military planners sweat. They sweat from the plain hard work of forging a superior armed force, and they sweat from worry. In an arena of such immense stakes and extensive U. S. commitments, the military services never seem to be provided in peacetime with sufficient means to attain the degree of national security they feel is required. Difficult choices must be made in allocating financial resources. When the pie is finally cut, it is inevitable that the big pieces will go toward the development of new military hardware, *i.e.*, combat equipment and weapons. In a world that reaches new technological frontiers almost daily, inferior arms invite disaster. If we must arm, we must arm well.

In a war a naval task force, however well armed, is a military asset only so long as it can keep fighting, preferably on the attack. It can keep fighting only so long as it has the means to do so. Although we can now forsee the basic logistic support requirements of an air-atomic navy in the years ahead, it is becoming increasingly apparent that we cannot hope to provide them at the outbreak of war. We cannot provide them because we we will not finance them. In the Olympian competition for coveted military appropriations, the gold awards are won every year by the more glamorous members of the defense team —combat planes, combat ships, and combat weapons. Although we know that strength in all departments is necessary for ultimate victory in any contest, we in America tend to depend upon the star performers in the main events to carry us through.

FREEDOM IS NOT FREE

The scientific revolution in which we live is nowhere more apparent than in the weapons we build. Because they are so complicated, modern combatant ships, aircraft, and other weapons command fantastic prices. A new destroyer contains forty times as many electron tubes as a 1937 model and costs as much to build as a cruiser formerly cost. Today's supersonic fighter planes are as big as World War II bombers and even more expensive. A modern jet interceptor requires more electronic equipment than a commercial television station. Tomorrow's superdestructive intercontinental missiles, now under development,

will cost an estimated one to five million dollars *each!*

Research, development, and equipment costs rival the altitude records set by ballistic missiles. A wind tunnel could be built in 1944 for $150,000. Now a Mach 3 wind tunnel costs $15,000,000. Rivet squeezers formerly purchased for $500-$1,000 each are being replaced by $80,000 automatic models. Most disturbing of all, the phenomenal pace of scientific discovery and industrial progress makes existing air-atomic and guided missile weapon systems obsolescent by the time we learn how to use them.

The inherent cost of increased performance and power in our armed forces is only part of the financial picture. The defense budget must also contend with the general rise in wages and prices in the U. S. economy. For example, although there has been a steady increase in the number of airframe pounds per manhour that can be produced in the U. S. aircraft industry, a skilled manhour costs almost twice as much in 1955 as in 1944. We get "more bang for a buck," but the buck keeps getting smaller. In addition, urgent demands for highways, schools, and other important social needs exert a continuous pressure to reduce military expenditures. The American defense effort each year becomes more and more a race between increased firepower and available taxpower.

The expanding volume of production and the increasing industrial and agricultural productivity in the United States could easily support higher defense expenditures. Economic or industrial capacity, however, does not establish the scale of our military preparations. It is the willingness of the people and their elected government officials to spend money for arms that normally sets the limits of defense spending in peacetime. This willingness depends upon a difficult judgment of costs and risks. The costs are certain, immediate, visible. The danger is uncertain, distant, and not always fully known or appreciated.

Almost two-thirds of a huge federal budget is appropriated for defense purposes now. This represents an enormous output of human energy and material resources every year. It annually approximates in monetary value the total gross national product of our strongest ally, Great Britain. It is the hope and goal of every administration and every Congress to cut military funds, not increase them.

Under these conditions, therefore, as weapons continue to rise in cost, less money will be available for support forces, unless weapons themselves or the training in their use are sacrificed—which is hardly likely. The disastrous double feature in Suez and Hungary, for example, revealed U. S. Air Force weakness in air transport strength. Troop carrier wings are reported to have been slashed from seventeen in 1953 to eleven this year as an economy measure during the same period that the B-52 program was stepped up. The wisdom of this decision can be debated endlessly. Since it is apparent that sufficient funds to finance both bombers and transports were either not requested or not made available, however, the odds are very high indeed that a decision would be made in favor of bombers.

The problem in the Navy is no different. Any recent Navy budget or shipbuilding program provides evidence that the solutions are inevitably and justifiably similar. The Fiscal Year 1957 program, for example, includes construction of 22 new combatant ships of the latest design and only one service force vessel—an ammunition ship. An attack transport and a seaplane tender are two out of eighteen conversions undertaken this year of ships already in naval service. Development of new type air transports required for support of an air-atomic navy is years behind the revolutionary progress in combat aircraft. This is regrettable but not necessarily reprehensible. It is primarily a matter of priority of need. The question that remains unanswered is whether or not the current technological explosion and inherent limitations on military funds in peacetime will ever permit adequate talent, money, and time to be diverted to what are judged to be lower priority tasks.

LOGISTICS SUBSISTS ON CRUMBS

We are victims of the irony of modern arms. While they consume funds that might otherwise be available for support functions, twentieth century weapons at the same time require the most advanced and extensive logistic support systems ever devised. Under even the most exacting management, such systems, if they are to be effective, are not cheap. If history is any guide, heroic efforts to create them in peacetime will be washed up on the sands of austerity.

To deplore the fact that progress in logistics has not kept pace with advances in combat equipment and weapons is not to say there has been little improvement in the field of logistics since 1945. There has been progress in shipboard handling equipment and underway replenishment techniques. There has been increased use of air transportation and electric accounting machines. Great strides have been taken in inventory control, traffic management, budgeting, food preparation, storage, and packaging. There is far more coordination and standardization among the military services along sound business management lines. Most of this progress, however, has been a consolidation or extension of developments begun during World War II or started as a result of lessons learned during that war. Progress there is, but it is lagging far behind the needs of World War III, if it comes.

Improvements in supply ships largely have been restricted to the modification of existing types, many of which were not originally designed for fleet issue tasks. When new support ships are constructed, like *Vega* (AF-59), *Suribachi* (AE-21) and *Neosho* (AO-143), they normally are born with one twin sister and regarded as modern prototypes of ships to be built in quantity in case of war. In the meantime, the re-

maining ships in the service forces continue to depreciate and become less capable of performing the tasks that would be required in the crucial, opening phases of war.

In addition, more ships are inactivated than are activated each year. In the Pacific Reserve Fleet during Fiscal Year 1955-56, for example, the ratio for major combatant and amphibious ships was three inactivated for every two activated; for auxiliary ships, four inactivated for every one activated. More auxiliaries were inactivated than were combatant and amphibious ships combined. Of significance also is the conversion of the only cargo submarine in the U. S. reserve fleet, *Barbero*, to a picket boat, with no announced plans for replacement.

The geographic range of fleet operations in Asian waters and the prudent dispersal of fleet units in WestPac ports has expanded the job to be done beyond the resources of the mobile support force. Increasing reliance is being placed upon supply support from repair ships and from politically and strategically vulnerable bases. Purchases in foreign ports from local sources of supply necessarily have become more common.

Ten years after Hiroshima the Marine Corps has its first converted carrier, *Thetis Bay*, to carry out its Number One task—atomic age assault by vertical envelopment. Only a financial windfall or an administrative miracle will yield the carrier-type support ships and transport type aircraft we need before the panic button is pushed again.

It was not for lack of vision that the advanced base program and mobile support ships were not ready for action until months and years after the Pearl Harbor attack. The need for these techniques, which were as essential to the Pacific campaign as fast carrier task forces and amphibious landings, was foreseen in the 1930's. Many within the Navy advocated their development then. This is only one of many examples of the Gordian knot into which military policy frequently is tied by strategic needs and financial limitations. The relationship between the immediacy of national danger and the availability of military funds is an historic one. It is the fundamental reason that the greatest forward strides in logistics have been made, and will continue to be made, *during* wars, not *between* them.

THE FLEET SUPPORT WE NEED

The combatant ship is the focus of all naval logistics effort. It is a vast and complicated undertaking to keep modern ships equipped to operate indefinitely in waters thousands of miles from home. Nuclear propulsion will bring mighty logistic gains to the fighting fleet by eventually reducing oiler needs and making available for storage of supplies much of the space now allotted to ships' fuel tanks. Nevertheless, jet aircraft, electronic detection systems, nuclear weapons, and guided missiles add staggering new dimensions to the problems of fleet maintenance and supply.

Modern weapons on the high seas require the most advanced and effective logistic support systems we can bring into being. Science, which has helped to create our problems, also ran help us to solve them. Techniques of operations research such as queuing theory, mathematical modeling, linear programming, probability theory, and game theory are useful tools in the fast-growing science of logistics. Electronic computers, data processing systems, and other progressive business management techniques also will provide invaluable assistance in the design of an optional system of naval supply.

It does not take an electronic computer, however, to visualize the fundamental principles which must govern a system of fleet supply support in the future. They emerge rather clearly from the character of atomic age task forces and the nature of modern global warfare anticipated in its most devastating form. The non-Communist areas along the borders of Europe and Asia constitute America's first line of defense. The water perimeter of free world nations on the Eurasian continent alone extends 22,000 miles, disregarding bays and inlets. Defense of this coastline and its strategic off-shore islands against Sino-Soviet aggression is a crucial part of the total task of policing 140 million square miles of free world oceans and seas. A high degree of defensive and offensive mobility is the only practical answer to this challenge.

Soviet military power—with or without atomic explosives—is especially designed to nullify America's greatest strategic assets. In case of war, hundreds of deadly steel sharks—Soviet U-boats—will swarm under the seas to destroy our ocean shipping and attack our coastal ports with guided missiles. Thousands of giant silver birds of many shapes will fill the skies to rain devastation upon our factories and cities. Our capacity for defense and retaliation will determine how successful the enemy's efforts to cripple U. S. industrial power and to prevent the support of overseas areas will be. Nevertheless, to remain effective in the face of such a potent threat, naval forces in distant waters must be relatively self-sufficient for extended periods of time.

A triumvirate of modern logistic concepts promises to give the Navy the endurance and mobility it needs. These concepts are endurance loading, mobile support, and air logistics. Afloat surveys have revealed that roughly 80 per cent of non-perishable general stores items carried aboard a combatant ship are low cost, small cube items of infrequent use. This material, as well as similar technical items, can thus be "endurance loaded" in sufficient quantity to last between vessel overhauls without increasing storage space requirements on board. The remaining 20 per cent of the bulkier, faster moving general stores items can be carried at ninety-day supply levels and replenished almost entirely from fleet issue ships.*

The food, fuel, and ammunition that combatant ships need can be provided entirely by underway re-

* Endurance loading, in combination with the Navy's simplified allowance lists (SAL) and the use of fleet supply research teams, forms the backbone of the current Atlantic Fleet Supply Readiness Improvement Program (FRIP).

plenishment at sea from the mobile support force. Technical repair parts and services are also available to a limited extent from tenders and fleet issue ships of the service force. Supply ships can satisfy 70-90 per cent of their customer's needs for various materials by stocking only 10 per cent of the thousands of items required by the fleet. The mobile support concept of carrying a small range of "best sellers" in quantity, plus a few critical insurance items, has proved both effective and economical. At the Pacific Fleet Supply Conference in February, 1956, the Commander, Service Force Pacific Fleet, demonstrated the value of mobile support. He told how five times as much naval ammunition was transported to the Pacific Theater during World War II as was used; whereas during the Korean War, the excess of ammunition was only 10 per cent, and most of this was in ammunition ships which could easily sail home after the war and unload.*

The indispensable but potentially weakest link in the fleet supply chain is the transportation pipeline. The items of material which are not endurance loaded in combat ships nor normally carried in the mobile support force must be ordered as needed from sources of supply in the continental United States. Stocks on board fleet issue ships must also be replenished or the ships themselves rotated. Dependable sea and air transport thus are required to provide a lifeline to overseas forces to keep the support system viable.

A naval operating force, then, is a mighty fist at the end of a long thin arm. In war the enemy will seek with all his strength to cut that arm to pieces. The Nazis almost succeeded in the Atlantic with an initial force of 57 submarines. The Reds have seven times that numerical strength—mostly late models. The Soviets also know how to manufacture and sow thousands of very effective mines. Whether the U. S. Navy's antisubmarine warfare measures and minesweeping techniques have advanced in proportion to the growing underseas threat is a question answered only in the laboratory of war.

The aerial element of the logistics arm is less vulnerable to interruption—at least in the air—than are ocean transports. But planes normally must have a terminal at which to land to deliver supplies. An air base that takes shiploads of men and materials weeks or months to build can be destroyed today by one bomb or missile in a few seconds.

The need for fast, flexible, and dependable pipeline support has given birth to the modern air logistics concept in the Navy. Although it is yet in the formative stages, this concept in its broadest sense envisages airlift of supplies to the fleet at sea by means of delivery to flat top fleet issue ships. These mobile air terminals in turn can make retail distribution to other ships of the task force during normal underway replenishment or by helicopter delivery.

The air logistics concept envisions greater use of airlift than has been employed in the past, including routine replenishment of selected materials to overseas ships and bases. Long range seaplane transports are believed feasible for support of water based attack aircraft and for supply of ships in protected coves or harbors—or even in the open sea. Seaplanes like the P6M SeaMaster should lessen considerably our present dependency upon overseas bases, particularly if refueling can be accomplished from submarine oilers modeled after the SSO *Guavina*. Nuclear-powered seaplanes, when they come, will bring with them a whole new era of air-atomic logistics.*

Airlift, however, for many, many years to come can provide only a partial answer to the problem of overseas pipeline support in time of war. The operation of large land-based aircraft probably generates more sea-lift requirements than it saves—mostly in base support and fuel. For each ton of cargo flown from the United States to Korea, four tons of gasoline must be supplied in advance for the return flight.

To build, operate, and maintain air transport squadrons places prodigious demands upon money, material, and skilled men. This is revealed in the high cost of airlift. It is currently over twenty times more costly to fly a carton of ships' parts to Manila than to ship them by ocean freight. Moreover, small aircraft cabin loads cannot begin to transport the tonnage required to support a war overseas. The tremendous airlift of Navy material to Korea in 1950 was a mere 1 per cent of sea-lift support.

For the foreseeable future, therefore, we cannot fly all our material over hostile submarines. Nor can we always evade or fight through them on the ocean's surface. However, this does not exhaust our means of averting the U-boat menace. We too can play the underseas game. By using submarines of modern design to transport cargo, we can employ the tactics of speed and stealth. During World War II plans were made but never used for underwater cargo carriers of 7,500 ton capacity. Next time we will need them. Bow-loading transport submarines could rendezvous with the operating forces and issue supplies underway. Fast, nuclear-propelled, undersea fleet-issue craft could be designed from the keel up to be reliable, versatile additions to the mobile support force and to the pipeline fleet.

This is the navy we need for survival and victory in global warfare, conventional or atomic. We need and will have fast-moving squadrons of surface ships and water-based bombers that can hit and run—and hit again. We need and will have ships that are constructed to withstand heat and blast and that can maneuver to avoid radioactive fall-out. We need and will have tactically dispersed task forces with their own active and passive air defense systems, including radar, supersonic fighters, tnd guided missiles. We

* The principles of endurance and mobility are firmly recognized in existing Pacific Fleet policies. Article 311 of U. S. Pacific Fleet Regulations states: "Fleet units operating West of Hawaii will be self-supporting or will normally be supported to the greatest extent practicable by mobile logistic support forces."

* The air logistics concept initially is being explored in its more technical supply aspects by Project FASTLANT (Fleet Air Support Test, Atlantic) and Project PACE (Pacific Air Cargo Evaluation). The results of these tests are expected to lay the foundation for the role that air transportation will play in navy supply support in the future.

need and will have hunter-killer groups to find enemy submarines and destroy them.

To keep the punch in this mighty fist we need and will surely have ships that can stay at sea for weeks at a time. However, we need and probably will not have enough mobile support ships of the right types. We need and undoubtedly will not have enough transport aircraft. We need and almost certainly will not have a number of cargo submarines.

In short, if and when World War III begins, we will not have the navy we need.

WHAT WE CAN DO

Surely military science and the art of naval warfare do not stand helpless before this administrative dilemma imposed upon them by public policy. All we really seek is an optimum defense, not a maximum one. The elusive quality of even more ephemeral goals than this, such as disarmament and peace, do not discourage us from ceaseless efforts in their behalf. Certainly more can be done to assure that our defenses are in the best possible balance to buy the most national security for the money we are authorized to spend. Logistic planners, rather than weeping over financial crumbs left at our disposal and making useless claims about what *could* be done *if* we had the funds we never will get, must take a more constructive course.

Four major areas immediately suggest themselves.

First, we must apply more scientific methods to determine how much and what kind of logistic support is essential to our force composition and to our naval strategy. There is a point at which the acquisition of ten more fighters could be less advantageous than the construction of a new tanker. Decisions of this kind need to be made every year. They are often a by-product of tests for logistic feasibility. At best they involve problems of staggering proportions requiring the combined judgment of many experienced and intelligent officers and naval civilians. Nevertheless, such decisions often must be made on an *ad hoc* basis without the benefit of a continuing, scientific methodology. A greater understanding and wider application of such techniques as von Neumann's theory of games is required for the planning of an air-atomic navy.

Second, improved management of the logistic resources we now have may enable us to divert "saved" funds to the new logistic tools we need. Although the incentive to economize in the military service is blunted by the fact that those who "save" money do not usually realize the benefits, perceptive top management decisions can result in increased effectiveness at less cost. One such area which requires our continued scrutiny is that of overseas shore activities.

Overseas naval bases, which have served us so well in the recent past, face a much less auspicious future. They are vulnerable to modern missiles. They are expensive to man, operate, and maintain. Approximately 80 per cent of Naval material shipped from West Coast ports every year, excluding bulk petroleum, is for support of existing Pacific bases. Moreover, modern war tends to overrun or run away from fixed land bases. We still need the services that bases provide, particularly for fleet aviation support, but a far-sighted and rigorous cost-risk-gain analysis is required in each case to determine how many of these functions in the long run could be performed more economically and safely afloat. The lip-service we give to mobile support should not be permitted to disguise the fact that we are becoming more, rather than less, dependent upon shore facilities overseas.

Overseas supply support, for example, might be rendered by a "naval fleet supply depot" comprised principally of nonself-propelled barges that could provide storage and transit shed facilities for pipeline support of the fleet in peace or war. Such an NFSD would be economical to establish and maintain. It would possess sufficient mobility to be towed to a new location or dispersed as required. Issues could be made to fleet units in port or delivered to the fleet in tankers, tenders, or supply ships. In combination with other local supply, repair and transportation facilities afloat and ashore in an overseas area, it would serve as a low-cost component of a relatively dispersed and semi-mobile naval base complex.

Costly naval shore installations could be further reduced by more extensive use of commercial facilities abroad. If vital support is kept organic to the fleet itself, there is no reason why contract logistics for the remaining naval services required cannot eventually be handled as successfully in friendly countries overseas as it has been at home.

The presence of small naval purchasing offices in major foreign ports to buy selected supplies and other logistic services for support of U. S. fleet units in an area has several advantages. It reduces the demand for overseas transportation and the risk of interruption of supply. It would be flexible. It could increase our sources of intelligence. It would assist in redressing the imbalance of international payments by enabling other nations to earn more dollars. Finally, it would develop the capability and skills in many industries and shipyards around the world to meet U. S. fleet requirements.

A philosophy of this kind must have inspired Admiral von Tirpitz to comment when he was trying to select a location for a German naval base in the Far East before World War I: "My chief demand was capacity for economic development; it did not seem advisable to me to establish a purely naval base."

It is in regard to this very question of indigenous support that the third major area of possible action to alleviate our logistic difficulties occurs. This third area is in mobilization planning.

Mobilization plans must prepare for the worst. They must provide for the almost certain eventuality of our being forced to fight without the support forces we would like to have. One outstanding lesson of the Korean War was that, in spite of the success of mobile supply support and pipeline replenishment during that campaign, American forces, including the Navy, turned to nearby Japan for substantial logistic assistance of all kinds. This support came from both

U. S. facilities and the Japanese economy. It will be recalled that Korean naval operations and subsequent East Asian patrols have been conducted with complete immunity from enemy attack. If, under these ideal conditions, the fleet is not self-sustaining, it is dismal to contemplate what will happen when missiles and bombs fill the air and submarines are everywhere.

It is not inconceivable, therefore, that in a future war U. S. task forces in distant waters may be isolated from logistic support for considerable periods of time. Pipeline ships will go down. Mobile support ships will be destroyed. Overseas bases, U. S. ports, and American sources of supply may be hit hard. Under these circumstances our forces overseas will need all the help they can get from our foreign friends.

American forces have been compelled to rely upon allied support before. During World War II "reverse lend-lease" amounted to about seven billion dollars. During the initial phases of the war, in particular, Great Britain in the Atlantic, and Australia and New Zealand in the Pacific furnished U. S. Army and Navy units with a small but very important margin of assistance.

This kind of emergency is even more likely to happen again. Although our military posture today dwarfs our state of readiness in 1941, we now have far greater commitments. We are logistically far more vulnerable than we were then. On this score Soviet underseas and air-atomic power and our chronic inability fully to prepare ourselves are the eloquent spokesmen.

Mobilization plans should provide for emergency commercial sources of off-shore supply and repair. Selected items of low cost, bulky materials also must be stockpiled overseas at strategic locations away from military installations. Within the limits of feasibility and common prudence, arrangements for foreign supply of non-technical and semi-technical materials and services should be an essential part of industrial mobilization planning for global war. Procedures for mutual support within NATO provide an excellent basis from which to begin.

Plans for off-shore supply are tantamount to the stock-piling of precious shipping space. They supplement the air logistics concept by reducing the need to fly low value, high cube cargo half way around the world. Our dependence on overseas bases, which offer far more tempting targets than widespread industrial facilities, will be lessened. The vulnerability of our means of support would thus be lowered even further by the immense area over which facilities for fleet supply and repair could be dispersed.

In conclusion, an ingredient essential to the success of the three proposed areas of action outlined above must be emphasized. This ingredient is the simple appreciation among military officers and defense officials of the range and depth of the field of naval logistics. Despite significant progress in recent years toward a recognition of its importance, logistics frequently still is regarded as something apart from, and inferior to, strategy, tactics, and weapons development.

Actually, as we have seen, logistics pervades the entire field of military science. There is no naval operation in which it does not play a vital part. But "beans, bullets, and black oil" do not possess the traditional glamour of ships, guns, and planes, nor the new excitement of atoms and missiles. It is only human to become fascinated by the extraordinary developments in the capital equipment of the modern navy. It is also in this capital equipment that our heavy financial investment lies, and where a man's investment is, there will his heart and mind be also.

The roots of naval logistics are buried deep in the nation's domestic and foreign economic policies. As long as national defense is as important to our society as it is today, naval leaders should have a voice in shaping these policies. To be able to do this, however, requires a capability within the organization of the Navy to discharge this challenging task. It demands an understanding of logistics that goes beyond plans for electronic computers and aerial delivery at sea, as important as these requirements are.

Such questions transcend logistics. They raise issues of maritime economic strategy which are as vital to the Navy as *Forrestal* and *Nautilus*. They involve reasons why government policies designed to reduce trade barriers, expand world commerce, and foster the economic growth of our allies and of underdeveloped nations of the free world deserve the strong support of the U. S. Navy—such reasons as the economic interdependence of maritime nations, multinational dispersal of industrial facilities, and offshore supply.

A global navy needs an economic policy just as it needs a weapons policy. It needs to help create the economic conditions and political climate in which logistic techniques that are developed can be applied.

National security henceforth must be more and more the produce of comprehensive and intelligent planning. We can no longer entrust our nation's safety to the largesse of good fortune as we have in the past. Our lives, the life of our country, and the hopes of free men everywhere are at stake.

W. LEE WILLIAMS

ALUMINUM BRONZES FOR MARINE APPLICATIONS

THE AUTHOR

received the degree of Bachelor of Science in Chemical Engineering in 1941 from Antioch College. During four of his student years he served under the cooperative plan as laboratorian in Physical Metallurgy at Battelle Memorial Institute. After graduation he became Metallurgist for the American Steel Abrasives Company. During the war he was commissioned in the Naval Reserve and served at the U. S. Naval Engineering Experiment Station. After discharge, he remained as a civilian metallurgist and is Head of the Physical Metallurgy Branch, Metallurgical Laboratory. Mr. Williams has been author or co-author of five previous articles in the JOURNAL.

INTRODUCTION

ALUMINUM BRONZES have rapidly increased in importance for uses on naval and merchants ships. This article has been prepared to highlight some of the properties of aluminum bronzes that would be of particular interest to the designer of shipboard machinery components. The information is based largely on experimental programs conducted by the U. S. Naval Engineering Experiment Station.

The Navy's interest in aluminum bronzes has been stimulated by three factors associated with the post World War II period. One was the desire to find substitutes for tin bronzes as a means of conserving tin. A second was the desire to find substitutes for copper-nickel and nickel-copper alloys as a means of conserving nickel. And third, the building of non-magnetic minesweepers introduced the problem of using non-ferrous materials in applications previously reserved for ferrous materials.

A fourth factor can also be added: there were indications that aluminum bronzes would be desirable for many applications on their own merits, in direct competition with other materials, and not merely as second-best substitutes.

ALUMINUM BRONZES DEFINED

Aluminum bronzes are copper-base alloys containing up to about 15% aluminum. Most of the important commercial alloys contain from 4 to 11% aluminum, and may contain additions of iron, nickel, manganese, silicon, and possibly other elements.

The term "bronze" commonly connotes copper-tin alloys, but the aluminum bronzes are essentially tin-free materials. Copper aluminum alloys with zinc as a major alloying element are sometimes called bronzes. However, these are better classed as aluminum brasses. The bronzes described in this article are essentially zinc-free alloys.

The strength and ductility of the binary copper-aluminum alloys increase progressively with aluminum content up to about 8.4%. Increasing the aluminum beyond this amount introduces a second phase which causes an abrupt increase in strength and decrease in ductility. The single phase alloys can be hardened and strengthened by cold work and are used chiefly in the wrought form. The duplex alloys can be cold worked only to a limited extent, but can be hardened by heat treatment. They are used in both the cast and wrought forms.

Modern commercial alloys usually contain alloying elements in addition to the aluminum. Iron and nickel may be added in amounts up to 5%, and manganese and silicon in smaller amounts, but as much as 12% manganese is added in at least one important alloy. The iron and nickel increase strength and hardness and assist in grain refinement. Manganese acts as a degasifier and grain refiner, and also improves strength. Silicon is added as a substitute for a part of the aluminum, especially to increase machinability. The alloys are versatile in that they can be cast, rolled, forged and extruded, and can be joined by silver brazing and welding.

HISTORICAL

The Engineering Experiment Station's first test report on an aluminum bronze was issued in June 1917. Test work was sporadic and limited in scope from then until the post World War II period. For the most part, the early experiments consisted of isolated measurements of mechanical properties and corrosion resistance, with little attempt to study the whole family of alloys systematically. However, some experiments were made to evaluate certain alloys for specific applications.

Early reports show that cast aluminum bronzes were considered for use in sea water lubricated ball bearings, but there is no record of actual use in this application. The cast bronzes were also evaluated for marine propellers. Some service use was made of the alloys for small submarine and tugboat propellers where high strength was needed. For the most part, these were made of 85-11-4 Cu-Al-Fe and 81-11-4-4 Cu-Al-Fe-Ni compositions.

Four grades of cast aluminum bronze were included at an early date in Navy Specification 46B18. The specification characterized the alloys as of "great strength with a hardness equal to that of manganese bronze, great resistance to corrosion, shock and fatigue, and suitable for gun slides, gun mountings, worm gears and wheels, valve seats, bearings and propellers." Nevertheless, except for occasional applications, most of the bronze castings used aboard ship were made of manganese, hydraulic, "G" or "M" bronzes.

Wrought aluminum bronzes also appeared at an early date in Navy Specification 46B17. Two grades were included: 95-5 Cu-Al and 89-8-3 Cu-Al-Fe. The specification characterized the alloys as "possessing greater resistance to corrosion than manganese bronze, and may be used where greater strength and resistance to corrosion are required. They possess good bearing qualities and may be readily forged. They are intended for uses such as valve stems, propeller blade bolts, air pumps, condenser bolts and slide liners." Despite the existence of this specification, no early large scale use was made of wrought aluminum bronzes for shipboard applications, although some limited use did occur in special applications.

Aluminum bronzes were never included in early Navy specifications for salt water piping and condenser tubing. These important applications were restricted for years to 70-30 copper-nickel, first of the low iron variety, and later with a nominal 0.5% iron content. The success of the 70-30 alloys in these applications left little to be desired from the performance standpoint.

Thus, the early history of the aluminum bronzes might be summarized as follows: the alloys were known and tested; they appeared in Navy specifications for cast and wrought products, except for salt water piping and condenser tubing, but they were not used extensively for shipboard applications, probably because of conservative designs and the tendency to continue the use of other copper-base alloys which were better known and were giving generally satisfactory service.

The increased interest in aluminum bronzes following World War II led to the conduct of extensive experimental programs. The remainder of this article highlights the results of some of these experiments.

MATERIALS

Specifications MIL-B-15939 and MIL-B-16033 are general purpose specifications for wrought and cast aluminum bronzes. From the standpoint of composition, they cover nearly all of the alloys commonly encountered. So for the sake of simplicity, this discussion will identify the various alloys mainly by reference to these two specifications.

This is not to say that other specifications are not in use. On the contrary, several others include aluminum bronzes for special applications, usually with minor differences in properties and compositions. For example, MIL-B-16166 is often used. This specification covers two heat-treatable forging alloys, similar in composition to two of the alloys in MIL-B-15939, but with higher strength requirements.

The chemical compositions and mechanical properties required by MIL-B-15939 and MIL-B-16033 are shown in Table I. The allowable ranges in composition are broad, so that more than one commercial alloy may qualify for any one of the specified grades.

The third column in the table contains a simple coding system which will be used to designate the alloys throughout the text. The letters "W" and "C" refer to wrought and cast, respectively. The numbers refer to the composition or class numbers. The letters "HT" refer to the heat-treated conditions in the cast alloys.

CORROSION PROPERTIES

General Corrosion. Water velocity is the most important single variable affecting the corrosion rate of aluminum bronze in sea water. The effect of velocity is illustrated by Figure 1, in which corrosion rates are given in IPY (inches penetration per year.

The corrosion rates shown on the graph were calculated as though the corrosion was uniformly distributed, even though a part of the corrosion may have been caused by local attack. More will be said later about the local forms of corrosion on aluminum bronzes. The rates on the graph were also calculated without regard to a number of other variables, such as air content of the water, seasonal changes in water temperature, seasonal changes in fouling conditions, and variations in alloy composition. It is clear, then, that these variables are of only secondary importance, and that water velocity is the predominant factor affecting the general corrosion rate. It is also clear that the corrosion rate varies almost linearly with velocity.

TABLE I

Chemical Compositions and Mechanical Properties Specified for Aluminum Bronzes [1]

Alloy	Condition	Alloy Code	Percent Composition						Minimum Properties [2]		
			Cu	Al	Fe	Ni	Mn	Si	Tensile Str., psi	Yield Str., psi	Elong., %
Wrought Alloys, Specification MIL-B-15939 [1]											
Comp. 1	Note (2)	W1	80.0–93.0	6.5–11.0	4.0 max.	1.0 [3] max.	1.5 max.	2.2 [3] max.	70000/80000	30000/40000	15/20
Comp. 2	Note (2)	W2	78.0–85.0	9.0–11.0	2.0–4.0	4.0–5.5	1.5 max.	0.25 max.	85000/105000	42500/55000	10
Comp. 3	Note (2)	W3	92.0–96.0	4.0–7.0	0.50 max.	..	..	..	45000/80000	17000/40000	25/40
Comp. 4	Note (2)	W4	90.0–93.0	7.0–9.0	0.50 max.	..	..	..	50000/65000	20000/27000	20/30
Comp. 5	Note (2)	W5	88.0–92.5	6.0–8.0	3.5 max.	..	1.0 max.	..	70000/85000	30000/55000	30/40
Cast Alloys, Specification MIL-B-16033 [1]											
Class 1	As cast	C1	86.0 min.	8.5–9.5	2.5–4.0	..	..	..	65000	25000	20
Class 2	As cast	C2	86.0 min.	9.0–11.0	0.75 1.5	..	..	..	65000	25000	20
	Heat treated	C2-HT	"	"	"	..	..	..	80000	40000	12
Class 3	As cast	C3	83.0 min.	10.0–11.5	3.0–5.0	2.5 max.	0.50 max.	..	75000	30000	12
	Heat treated	C3-HT	"	"	"	"	"	..	90000	45000	6
Class 4	As cast	C4	78.0 min.	10.0–11.5	3.0–5.0	3.0–5.5	3.5 max.	..	90000	40000	6
	Heat treated	C4-HT	"	"	"	"	"	..	110000	60000	5

Notes: [1] Other specifications are also in use. See text.
[2] Minimum properties shown for MIL-B-15939 vary over the ranges indicated. Specific minimum values depend on section size, shape, temper and method of manufacture. See specification for details.
[3] When both Si and Ni are present, only one shall be in excess of 0.25%.

The three wrought aluminum bronzes shown in Figure 1 have similar corrosion rates. Thus, factors other than general corrosion resistance would influence the selection of one alloy over another. Such factors would include strength, cost, critical alloy content, fabricating characteristics, and available mill forms.

Another factor in alloy selection would be relative resistance to local attack, such as pitting. This would be especially important for wrought material used in thin sections, or for heavier sections where smooth working surfaces must be maintained. Local attack would be important mostly at low water velocities where general corrosion rates would also be low.

At high water velocities, the general corrosion rates of the wrought bronzes are higher and of greater significance. If the rates for the aluminum bronzes are excessive for satisfactory performance, there is little choice but to go to a more resistant type of material, such as nickel-copper or copper-nickel.

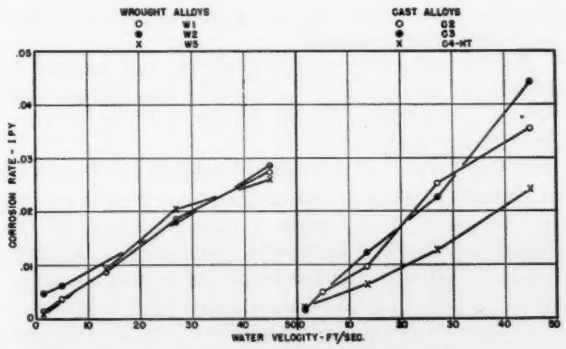

Figure 1. Relation between water velocity and general corrosion rate for aluminum bronzes tested in sea water.

The cast aluminum bronzes shown in Figure 1 also have corrosion rates that vary almost linearly with water velocity. The corrosion rates of the cast alloys are of the same order as those of the wrought alloys,

but there is more spread among the cast alloys. The most resistant alloy is C4, of the 11-4-4 Al-Fe-Ni variety.

The Navy's cast Composition G and Composition M tin bronzes are roughly in the same class of corrosion resistance as cast aluminum bronzes. At the higher water velocities, manganese bronze is decidedly inferior, and cast copper-nickel-silicon alloy is markedly superior.

Cast bronzes ordinarily are used in heavier sections than wrought bronzes. Thus, local pitting attack may not be so important for cast bronzes, unless it is necessary to maintain a smooth working surface.

Local Corrosion. Local accelerated attack of aluminum bronzes may occur in several forms. Two forms often observed are pitting and crevice corrosion. Pitting is corrosion that develops in highly localized areas on a metal surface that is not attacked elsewhere to any great extent. Crevice corrosion is corrosion that occurs within or adjacent to a crevice formed by contact with another piece of the same or another metal or with a non-metallic material.

In general, the aluminum bronzes most susceptible to one of these forms of attack are also the most susceptible to the other form of attack. The action usually is more severe in stagnant or slowly moving water than in rapidly moving or turbulent water.

The extent of attack depends on the environment and the alloy composition. Tests in sea water and brackish Severn River water have produced attack in one environment or another in all alloys tested (W1, W2, W5, C2, C3 and C4). Poorest resistance was found in alloys W2 and C4.

Specimens exposed 345 days in slowly moving sea water (1.5 ft/sec) are shown in Figure 2. The effects of both pitting and crevice corrosion are apparent. The latter occurred under and around the non-metallic mountings and at occasional areas where barnacles were attached.

Pitting and crevice corrosion are not unique to aluminum bronzes, as evidenced by the Composition G and Composition M tin bronzes shown for comparison in Figure 2.

A third form of local attack sometimes found on aluminum bronzes is dealuminization. This is caused by corrosion of the alloy and redeposition of the copper in situ. The process is analogous to dezincification in brasses. Dealuminized areas can be recognized by their distinct copper color.

Dealuminization has been observed to some extent in alloys W1, W2, C2 and C3. It is sometimes found where crevice corrosion has occurred. But its most common location is at the waterline of partially immersed pieces. The worst case observed in any test was on an alloy C2 specimen partially immersed in brackish Severn River water. The dealuminization penetrated 0.07" in nine months.

A fourth form of local corrosion is impingement

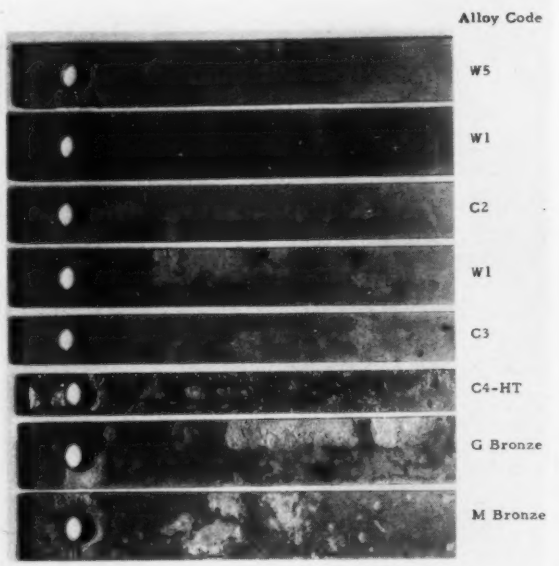

Figure 2. Aluminum bronze and tin bronze specimens after 345 days of exposure in sea water flowing at 1½ ft./sec.

attack, which is corrosion associated with turbulent flow. This type of attack is commonly found at the inlet ends of condenser tubes, and in pipe lines downstream of fittings.

An apparatus to study impingement attack has been developed by the British Nonferrous Metals Research Association. Basically, the test consists of a jet of water impinging on a flat specimen surface. The specimen is placed 2 mm from the tip of the jet. Both specimen and jet are immersed in water during operation.

Sea water impingement tests were made with this apparatus for 30 days at a jet velocity of 15 ft/sec. The water contained 2 to 4% air by volume. Average results, consisting of measurements of depth of attack, are listed in Table II for several aluminum bronzes and comparison alloys.

A fifth form of accelerated attack can be caused by galvanic action. This may be general or local, depending on various circumstances. But the more troublesome type is usually a local accelerated action at areas where dissimilar metals are in physical contact.

It is possible to list metals and alloys in order of their relative potentials in a given environment. Such a list, called a galvanic series, is helpful in predicting possible trouble-areas. Combinations of alloys with different potentials can result in accelerated corrosion of the less noble material, and the situation usually becomes more aggravated as the alloys become farther apart in the galvanic series.

Potential measurements of aluminum bronzes were made in sea water flowing at 13 ft/sec, using an apparatus developed by the International Nickel Company, Incorporated. The potentials were meas-

TABLE II
Average Results of Jet Impingement Tests

Alloy	Max. Pit Depth, inches
Aluminum Bronzes	
W1, forged, 89–9.5–1.5 Cu-Al-Fe	0.004
W1, forged, 86–10.5–3.5 Cu-Al-Fe	0.010
W1, extruded, 87–9.5–3.5 Cu-Al-Fe	0.031
W2, forged, 81–10–3–5–1 Cu-Al-Fe-Ni-Mn	0.009
W2, extruded, 81–10–3–5–1 Cu-Al-Fe-Ni-Mn	0.004
W5, rolled, 90.5–7–2.5 Cu-Al-Fe	0.012
W5, extruded, 90.5–7–2.5 Cu-Al-Fe	0.008
C2, cast, 88.5–10.5–1 Cu-Al-Fe	0.021
C3, cast, 86–10.5–3.5 Cu-Al-Fe	0.008
C4-HT, cast, 80.5–10.5–4.5–4.5 Cu-Al-Fe-Ni	0.010
Comparison Alloys	
Nickel-copper, rolled	0.001
Copper-nickel, 70–30, rolled	0.005
Copper-nickel, 90–10, rolled	0.011
G Bronze, cast	0.004
M Bronze, cast	0.003
Mn Bronze, cast	0.015
Nickel-copper-silicon, cast	0.000

ured with a saturated calomel half cell and a potentiometer. The average results for several materials during the final 200 hours of a 718-hour test are listed in Table III. It is evident that the aluminum bronzes have potentials within the range of other corrosion-resistant materials commonly used in sea water environments.

Effect of Welding. Welded aluminum bronzes were tested for corrosion resistance in several environments. The alloys included C2, C3-HT, W2 and W5. Each of these was welded in two ways: (1) heliarc welded with 89-10-1 Cu-Al-Fe rods and (2) carbon-arc welded with 85-11.5-3.5 Cu-Al-Fe rods. The welding produced no significant change in corrosion properties, and no serious galvanic corrosion occurred between the base alloys and weld deposits.

Stress Corrosion. Experiments conducted to date have indicated that aluminum bronzes are not susceptible to stress-corrosion cracking in marine environments. This seems to be substantiated by service experience. The author has no knowledge of any aluminum bronze having failed from exposure to sea water or marine atmosphere. Several failures of "aluminum bronze" were looked into, but in each case the material actually was found to be a high-tensile brass (commonly called aluminum-manganese bronze).

This is not to say that stress corrosion will not occur in aluminum bronzes exposed to other environments. A notable example was the failure of W5 alloy in a vapor-compression still. Failure occurred from exposure to hot fresh water and water vapor near welds and a cold-upset flange. The unit had not been stress relieved after fabrication. Stress relief was recommended as the principal remedy to the problem. Tests of unstressed specimens, in which stress corrosion is not a problem, showed that aluminum bronzes suffer negligible corrosion in fresh water distilling plants.

TABLE III
Sea Water Potential Measurements, Negative to Saturated Calomel Half-Cell

Alloy	Potential volts
Aluminum bronze W1 (1.5% Fe)	0.34
Aluminum bronze W5	0.31
Composition G bronze	0.31
Copper-nickel (70–30)	0.25
Aluminum bronze C2	0.23
Aluminum bronze C3	0.22
Aluminum bronze W1 (3.5% Fe)	0.18
Aluminum bronze C4	0.13
Nickel-copper	0.08

Fouling. Aluminum bronzes are subject to varying degrees of marine fouling in quiet sea water and brackish estuary water. The extent of fouling does not seem to bear a clear relation to the corrosion rate of the aluminum bronzes. In other words, the amount of copper released by corrosion does not seem to correlate with the toxicity to fouling organisms.

Fouling on specimens immersed one year in brackish Severn River water is illustrated in Figure 3. Fouling is not a problem on aluminum bronzes in water moving at velocities of about 1.5 ft/sec and higher.

FATIGUE AND CORROSION FATIGUE PROPERTIES

Representative fatigue and corrosion fatigue properties of aluminum bronzes and other selected alloys are listed in Table IV. The fatigue strengths are shown as estimated at 10^8 stress cycles when tested at 1450 cycles per minute.

The ratio of the fatigue strength in air to the tensile strength provides a useful basis for judging the characteristic behavior of the alloys. The ratios for the wrought aluminum bronzes are about normal for non-ferrous materials, and compare favorably with wrought nickel-copper and nickel-copper-aluminum alloys. The ratios for the cast aluminum bronzes

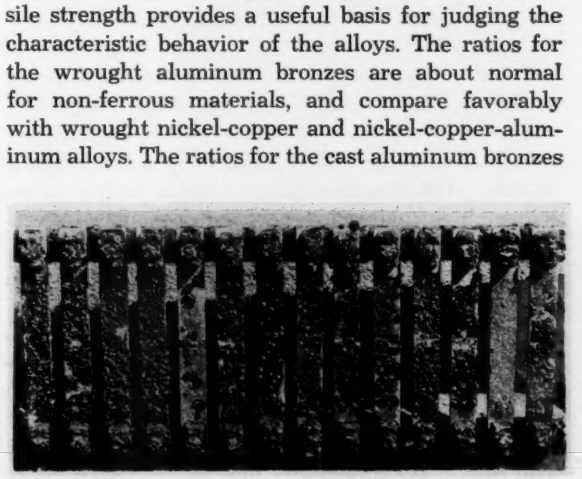

Figure 3. Fouling on aluminum bronze specimens after one year of exposure in quiescent brackish Severn River water.

TABLE IV

Estimated Fatigue Strength of Aluminum Bronzes and Comparison Alloys at 10^8 Cycles Tested at 1450 CPM

Alloy	Tensile Strength, psi	Fatigue Strength, psi					
		Rotating Bending				Alternating Torsion	
		In Air	Ratio to Tens. Str.	In Brackish River Water	In Sea Water	In Air	Ratio to Tens. Str.
Wrought Alloys							
W1 Lot 1	84800	25000	0.30	19000	18000		
Lot 2	90400	28000	0.31	19000	19000		
Lot 3	99000	35000	0.35			17000	0.17
W2 Lot 1	109000	33000	0.30		20000	17500	0.16
Lot 2	109000	25000	0.23				
W3 Lot 1	71900	19000	0.26			11000	0.15
W4 Lot 1	83400	29500	0.35			13000	0.16
W5 Lot 1	76200	24000	0.32	16000	15000		
Lot 2	90400	32700	0.36	24000			
Ni-Cu-Al	160800	47000	0.29	36000			
Ni-Cu	81900	26000	0.32	28000			
Cast Alloys							
C2 Lot 1	73600	24000	0.33	16000	15000		
C3 Lot 1	89400	25000	0.28	18000	18000		
Lot 2	85000	25000	0.29	23000			
C3-HT Lot 1	115600	36000	0.31		25000	17500	0.15
Lot 2	108500	30000	0.28				
C4 Lot 1	97700	24500	0.25		18000	14000	0.14
Lot 2	91000	19000	0.21		17000	14000	0.15
Lot 3	97500	28500	0.29	24500			
Lot 4	88000	23000	0.26	19500			
C4-HT Lot 1	117800	35000	0.30	27000	27000		
Lot 2	110600	32000	0.29		22000	13000	0.12
Lot 3	116800	31000	0.27	17500			
Al-Mn Bronze	110800	16000	0.14	16000			
Ni-Cu-Si	136500	16000	0.12	13000			
Mn Bronze	73200	9000	0.12	9000			

are also normal for non-ferrous alloys, and indeed are on the high side for cast copper-base alloys.

Occasional low ratios were observed in tests of aluminum bronzes. In each case, this could be traced to poor material quality or to unusually large sections from which the specimens were removed. Sometimes, also, a material would have good bending fatigue properties and poor torsional fatigue properties. This usually resulted from pronounced directional properties in wrought products.

Some of the aluminum bronzes have tensile properties equivalent to low and medium strength steels. However, this does not mean that size-for-size substitution can be made in applications involving fatigue resistance. The fatigue strength to tensile strength ratio for steels is usually in the range of 0.40 to 0.50, and this range is considerably higher than that of the bronzes.

The corrosion fatigue properties of aluminum bronzes are considered good for copper-base alloys. The resistance to corrosion fatigue is about the same in brackish Severn River water as in sea water.

MAGNETIC PROPERTIES

The magnetic properties of feebly magnetic materials are of interest for applications on nonmagnetic minesweepers. The magnetic permeability of many aluminum bronzes has been measured with a Fahy Low-Mu permeameter at 100 oersteds. The highest value recorded was 1.35 in an extruded 85.5-11-3.5 Cu-Al-Fe material.

The magnetic measurements showed that iron was the only element that affected the permeability of these alloys. The normal permeability was 1.00 in every instance where the iron content was low. However, there was no simple relation between the iron content and permeability, as the permeability was structure sensitive, i.e., it varied with casting conditions, heat treatment, rate of solidification, amount of hot work, etc. Whether the condition was

cast or wrought had no direct bearing on permeability.

SPECIFIC APPLICATIONS

It is apparent from the foregoing sections that aluminum bronzes could be used for a wide variety of shipboard hardware. In many cases, satisfactory performance would require only that designs be compatible with the corrosion and mechanical properties as determined by the usual "coupon" tests.

But there are also applications, the suitability of which cannot be predicted accurately on such a simplified basis. These applications require more elaborate study, perhaps in the form of simulated or actual service tests. A few examples will be cited.

Salt Water Piping. For many years the Navy used 70-30 copper-nickel alloy for salt water piping. The alloy originally was made with a low iron content, and then later was modified to contain a nominal 0.5% iron to enhance corrosion and erosion resistance. In more recent years, the Navy has used a 90-10 copper-nickel alloy, with a nominal 1.5% iron, as a means of reducing cost and conserving nickel. The iron-modified cupro-nickels have provided satisfactory performance, with long life at designed water-flow velocities up to 15 ft./sec.

The desire for still cheaper materials and complete elimination of nickel led to the study of several alternate alloys. Of special interest were an aluminum brass (76-22-2 Cu-Zn-Al) and two aluminum bronzes, W3 (95-5 Cu-Al) and W5 (91-7-2 CU-Al-Fe).

Piping systems of these alloys, and of copper-nickel for comparison, were set up and operated with natural sea water at the Harbor Island Test Station, Wrightsville Beach, North Carolina. The water was pumped through the pipes at two velocities: 11 and 15 ft/sec. The piping systems contained various types of fittings, including valves, tees, ells, unions, flanges, dead ends, etc., so as to stimulate flow conditions in actual installations.

The two aluminum bronzes and the aluminum brass were in good condition after two years of operation at 11 ft/sec. Erosion was practically nil, and the pipe walls were only slightly roughened from corrosion.

The situation was somewhat different at 15 ft/sec. About 70% of the W3 aluminum bronze alloy pipes had failed by perforation within 18 months. Failures occurred from both erosion and pitting, but pitting was the more serious form of deterioration.

Better performance was obtained with the W5 aluminum bronze alloy at 15 ft/sec. However, two out of ten pipe sections were perforated within 29 months. Pitting and erosion were again found to be the cause of failure. Figure 4 shows a W5 alloy pipe which failed after 17 months in the turbulent area just downstream of a long radius elbow.

No failures developed in the aluminum brass piping over a 26-month test period at 15 ft/sec. However, some erosion and pitting had occurred, especially in turbulent areas immediately downstream of fittings. The deepest pits were about 20 mils deep.

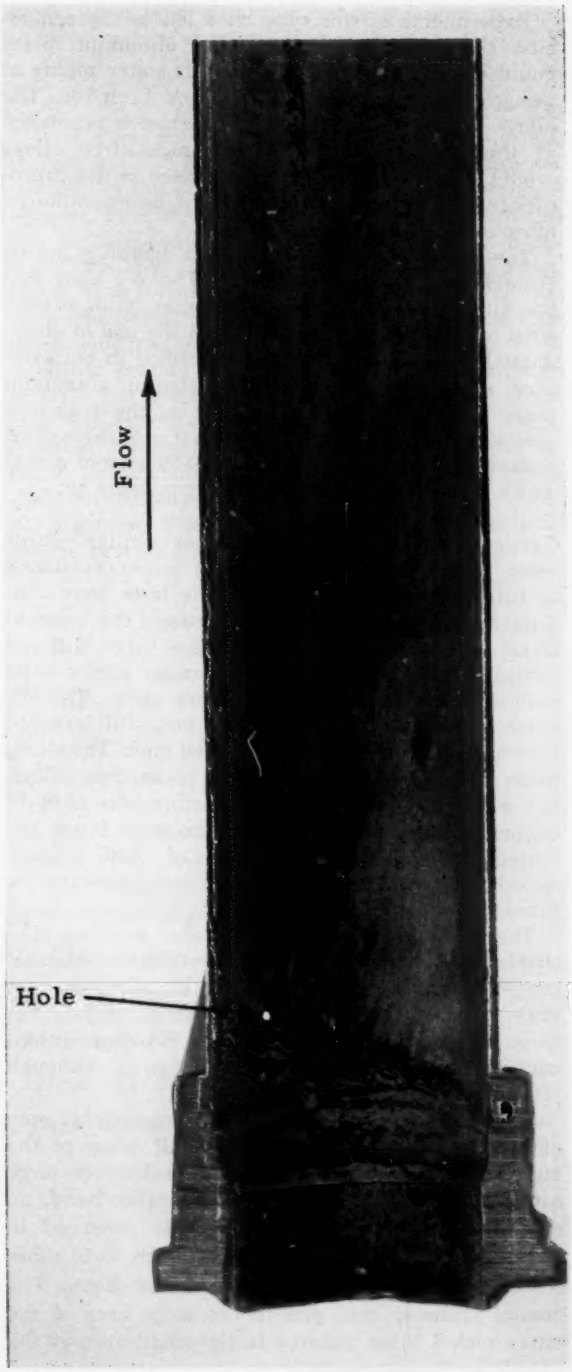

Figure 4. Aluminum bronze (W5 alloy) pipe which failed downstream of a long radius elbow after 17 months of test with sea water flowing at 15 ft./sec.

Experiments of this type have led to the conclusion that aluminum bronze and aluminum brass could be used with success for salt water piping at design velocities up to about 10 or 11 ft/sec. The alloys would provide fairly good erosion resistance at this velocity. However, the nickel-free alloys would not match the pitting resistance of the cupronickels. So eventual failures might be encountered after several years of service.

The W3 aluminum bronze would definitely not be suitable for piping at 15 ft/sec. The W5 alloy and the aluminum brass would be better, with preference for the latter. However, even the use of aluminum brass would entail some sacrifice in performance. At 15 ft/sec., it is unlikely that an aluminum brass system would last as long as the high-iron varieties of copper-nickel, although it probably would outlast the low-iron variety of 70-30 copper-nickel which was used in naval vessels some years ago.

Condenser Components. Somewhat similar results were obtained with these alloys when evaluated as tubes in model condensers. The tests were conducted with sea water flowing through the tubes at about 9 to 10 ft./sec. The W3 alloy tubes suffered considerable corrosion-erosion damage at the inlet ends and extensive pitting in other areas. The W5 alloy tubes were much better, but still suffered corrosion-erosion damage at the inlet ends. The aluminum brass was the best of the nickel-free alloys, but would not quite match the performance of 90-10 copper-nickel. However, the aluminum brass did outperform the low-iron variety of 70-30 copper-nickel which was specified until a few years ago for tubes in naval condensers.

The W3 and W5 alloys were also tried as tube sheets and water boxes in model condensers containing 90-10 cupro-nickel tubes. The W3 alloy was not very satisfactory in either application, largely because of excessive local pitting. The W5 alloy showed considerable promise in this application, although pitting was present to some extent.

Tests have indicated that 90-10 copper-nickel may suffer galvanic corrosion when small areas of the cupro-nickel alloy are coupled to relatively large areas of aluminum bronze. On the other hand, no significant accelerated corrosion was observed in two-year model condenser tests in which 90-10 tubes were used with aluminum bronze tube sheets. The reason probably was due to the large area of the cupro-nickel tubes relative to the small area of the aluminum bronze sheets.

The apparent compatability of the two alloys for condenser service was supported by examination of a cooler which had been in continuous use aboard a tanker for 14 years. The tubes were of 70-30 copper-nickel, and the tube sheets were of W2 aluminum bronze. Both materials were found to be in near perfect condition.

Valve Trim. Aluminum bronzes have been evaluated for stems, seats and discs in Navy Standard bronze globe valves. Present valves ordinarily use nickel-copper alloy for these parts, and conservation of nickel is the main attraction toward other materials. The globe valves are used aboard ship for fresh water, salt water, certain nonaqueous liquids and steam, up to 200 psi and 425°F.

The aluminum bronze valve parts were tested under various conditions of simulated service, as follows:

(1) Stem wear during 10,000 cycles of valve opening and closing to a torque of 100 inch-pounds, with brackish Severn River water in the valve at 100 psi.
(2) Stem wear during 5,000 cycles of valve operation on steam at 350–400° F and 140–260 psi.
(3) Crevice corrosion tests under gland packings during 7 months in flowing sea water and 15 months in quiescent sea water.
(4) Stem, disc and seat corrosion and erosion during 17.4 months of operation on sea water which was pumped through the lines at 10 to 15 ft./sec.

Experiments of this type indicated that satisfactory service should be obtained with valve stems made of W1 alloy (91-7-2 Cu-Al-Si) and W5 alloy (91-7-2 Cu-Al-Fe). Alloys W2 and W5 were tried for seat and disc applications, but were not considered satisfactory. The seats and discs eroded excessively in sea water service, especially under valve-throttling conditions, so that after a time the valves could not be shut off.

Propellers. It is difficult to adequately evaluate a material for marine propellers without actually trying it in propeller service. The matter is complicated by a lack of agreement as to the most desirable properties required of a good propeller alloy. Among the properties most commonly desired are: high strength and hardness, yet combined with good ductility and toughness; high resistance to corrosion fatigue; high resistance to cavitation erosion; good castability; good repairability by welding; and low cost.

Which of these properties might be of most importance would depend to a great extent on the type of service desired. High strength and toughness would be needed on tugboats and icebreakers. High strength and corrosion fatigue resistance would be needed for any propeller designed with thin blades. PT boats would need these attributes combined with cavitation resistance. Good castability, repairability and low cost would be of great importance for propellers on most large ocean-going vessels.

Laboratory studies have shown that some of the aluminum bronzes have good all-around properties. Some early use was made of aluminum bronze for small propellers. But until recently, manganese bronze had a monopoly on large propellers. Probably the greatest deterrents to the use of large aluminum bronze propellers were higher cost and fear of inadequate castability and weldability.

These difficulties have recently been overcome, first in Europe, and now in the United States. It is of interest that large aluminum bronze propellers have performed very well and have proved to be economical. A number of large aluminum bronze propellers have been cast in the United States, with several in the 30,000-pound class, and at least one weighing as much as 44,000 pounds.

Domestic production seems to be paralleling European practice in the selection of alloy compositions. One alloy corresponds to alloy C4, and contains nominally 10-5-5-1.5 Al-Ni-Fe-Mn, balance copper. Another is a high-manganese modification, such as 8-2-3-12 Al-Ni-Fe-Mn, balance copper.

Other Uses. The above examples represent only a few of the uses for which aluminum bronzes have been utilized or considered for utilization. Other applications, for either military or merchant vessels, have included pumps, bolts, heat exchanger parts, fresh water stills, outboard shafting sleeves, rigging parts, gears, and numerous other components. But there is not the space to discuss these items here.

CLOSURE

It is apparent that substantially good physical, mechanical and marine corrosion properties are obtainable in the family of alloys known as aluminum bronzes. It is also apparent that aluminum bronzes can be used for a wide variety of shipboard hardware, provided designs are consistent with the properties. It is important, however, that the individual alloys be screened carefully in selecting materials for specific applications.

Within certain limitations, the use of aluminum bronzes can affect savings in cost and critical materials. Depending on the application, their use in lieu of other materials may result in poorer, equal or better performance. In general, however, the aluminum bronzes are gaining greater recognition as useful alloys on their own merits, and not merely as second-best substitutes for something else.

Initial work on the first nuclear powered merchant ship was recently announced by the contract award (to B&W) for design, development and fabrication of the reactor and components for the propulsion plant. A pressurized water reactor with a low fuel enrichment, it will be capable of developing 20,000 SHP continuous output, 22,000 SHP maximum. It will power, in addition to the propulsion plant, the electrical system, heating system and cargo-handling equipment.

"THE SHIP-BUILDER AND MARINE ENGINE-BUILDER"

TECHNICAL PROGRESS IN SHIPBUILDING DURING 1956

ACKNOWLEDGEMENT

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As in previous years, comment on the world shipbuilding position at the commencement of this technical review of shipbuilding is fitting, and, once again, reference is made to the latest available information provided by Lloyd's Register of Shipping.

The first point which emerges from a review of the figures for the quarter ended 30 September, 1956, is that, in the field of production, Japan takes first place. Quoting the figures of ships completed in that quarter, as a criterion of the production rate, we find that Japan completed 80 ships of 416,689 tons gross. The next country is Germany, with 103 ships of 282,053 tons, and then come Great Britain and Northern Ireland, with 61 ships of 244,786 tons. Japan's large tonnage figure is, undoubtedly, partly due to the large tankers she is building.

Turning now to the figures for ships under construction, we find that Britain is in the lead, with 333 ships of 2,077,976 tons gross, representing nearly 28 per cent of world construction. Japan and Germany come second and third, respectively.

So far as Britain is concerned, the oil-tank ship represents the largest single type under construction, there being 58 vessels of this type, of 842,564 tons gross, under construction in British yards. However, on the basis of numbers, the cargo liner takes first place, with 95 ships of 675,376 tons. The cargo tramp accounts for 30 ships of 193,371 tons, while passenger and passenger/cargo types total 18 vessels of 158,625 tons. It is noteworthy that ore-carriers account for 12 ships of 123,730 tons. The oil-tank ship still maintains its position in world shipbuilding, the total tonnage under construction being 2,993,201 out of a total, for all types of ships, of 7,223,004 tons. How the situation in the Middle East will affect the tanker-building program, if at all, it is difficult to say; neither can one judge, as yet, if the blockage of the Suez Canal is likely to cause a modification in the policy with regard to tanker-building.

Finally, in considering the building figures, it may be noted that, of the ships being built in this country, some 73, of 486,286 tons gross, are for registration abroad. This may be taken as a measure of the export trade in this country, so far as shipbuilding is concerned.

With the increasing sizes of some of the types of ships under construction, and particularly the oil-tank vessel, the question of adequate facilities for repairs has become an urgent problem in this and other countries. It is gratifying, therefore, to note that, in so far as this country is concerned, ship-repairers are taking steps in the right direction. During the year, information has been made public with regard to some of the new docks being constructed on the River Tyne. A paper dealing with this subject was read before the North-East Coast Institution of Engineers and Shipbuilders in February, 1956. The new dry-docks discussed in this paper were those of Smith's Dock Co., Ltd., at North Shields, Messrs. Brigham & Cowan, Ltd., at South Shields, and Messrs. Swan, Hunter & Wigham Richardson, Ltd., at Wallsend. The dimensions of these three docks are, respectively, 709ft. by 95ft., 715ft. by 95ft., and 715ft. by 105ft.

SHIP DESIGN

During the year under review, a ship of interest which has entered service is the *Bergensfjord*. An account of this ship was given in a paper to the North-East Coast Institution of Engineers and Shipbuilders by Mr. K. Haug and Mr. N. Carter, towards the end of the year. One of the features of the ship is the aluminum superstructure. The particular interest, here, lies in the fact that it represents the largest aluminum superstructure yet to be built in this coun-

try. Further, the material is all welded, and this must be the largest welded marine structure, in aluminum, in the world. It is understood that the use of aluminum in this ship was of great assistance to the designers, and this venture will, no doubt, lead the way for future aluminum structures.

Another ship of particular interest is the *Empress of Britain,* built by the Fairfield Shipbuilding and Engineering Co., Ltd., for the Canadian Pacific Railway Company's fleet. The new ship is very modern in appearance and has dimensions of 640ft. by 85ft. The service S.H.P. is 27,000, which gives a speed of 20 knots. The structural design of the ship incorporates a combination of longitudinal and transverse framing, and welding is employed to a great extent.

In dealing with the design of ships, it is convenient to mention some matters which have been discussed before the various technical societies throughout the year. Two papers delivered in the United States at the May meeting of the American Society of Naval Architects and Marine Engineers might be discussed first. The first of these papers, presented by Mr. James Gilmore, is entitled "The St. Lawrence River Canal Vessels." In his introduction, the author states that, when the St. Lawrence Seaway project is open to shipping, a type of ship long familiar in the St. Lawrence and the Great Lakes will become obsolete, to all intents and purposes. The paper traces the history of these ships and shows their development. Descriptive photographs and drawings are given of the various types of ships which have been used in the canals. It may be argued that a consideration of ships which are soon to be relegated to an inferior rôle, can hardly be called technical progress, yet the development of these ships, to suit particular circumstances, must be regarded as a good example of the design method and one which is worthy of study.

The other American paper to which reference has been made is also concerned with the St. Lawrence Seaway. This paper, entitled "The Economics of Future European-Great Lakes Freighter Service," is by Mr. Sydney A. Vincent. The paper shows that limited-draft sea-going freighters of 400ft. to 440ft. in length, and with a speed range of 14 to 18 knots, can transport, economically, general mixed cargoes between Europe and Lake Erie, *via* the St. Lawrence Waterway, during the seven-month ice-free season. It is suggested that, during the remainder of each year, the vessels operate between Europe and an Atlantic Coast port, and that the cargo be transported overland to the mid-west. The cost of transportation is presented with and without subsidies, and it is concluded that it would be cheaper and quicker to transport mid-west cargo *via* the St. Lawrence Waterway than *via* coastal ports during the ice-free season.

Another paper on a design problem, this time in warships, has been read at the May meeting of the American Society of Naval Architects and Marine Engineers. This paper is by Constructor Commodore Rowland Baker, R.C.N., and deals with habitability in ships of the Royal Canadian Navy. The author describes the factors leading up to the decision to revise, completely, and habitability arrangements in ships of the Royal Canadian Navy. Descriptions are given of these features as they are to-day, and, in particular, reference is made to the change-over from hammocks to bunks, and the change from the old British system of feeding to the cafeteria and dining-hall system. Plans are included of the accommodations in modern ships. Although improvements can be made by re-arrangement of existing spaces, many improvements can only be adopted if some space and weight are provided. It is interesting to note that the increases in weight and space required are not considered prohibitive.

In yet another paper read before the American Society of Naval Architects and Marine Engineers, in November last, the air-conditioning of modern tankers and cargo ships has been considered. The authors of this paper—Mr. George B. Johnson and Mr. D'Arcy E. Phillips—discuss the air-conditioning plant for the living quarters of a group of four supertankers, which went into service in 1954. Details of six different types of air-conditioning systems, suitable for use in tankers and cargo ships, are described, and trends in marine air-conditioning are discussed. The authors state that the extent of air-conditioning in marine practice is lagging behind that in land practice, but they foresee that air-conditioning on board ship will increase in the future. This paper represents a very worthy addition to the literature on this most important aspect of design.

Finally, in connection with design problems, reference is made to a paper entitled "Cargo-handling Appliances," by Mr. L. T. Norton, read before the Institution of Engineers and Shipbuilders in Scotland. Cargo-handling is a very important matter in the modern ship, and there seem to be a wide range of opinion on the subject, from those who consider that the ship itself must carry the most efficient and time-saving equipment, to those who believe that cargo-loading and unloading gear ought to be provided by the ports to which ships trade. However, Mr. Norton's paper is concerned with the gear normally to be found on board ship, in the form of winches and derricks.

The author's suggestions as to features which would lead to efficient cargo-handling and the effect of these on the general design will be of interest to all ship designers. He considers that accommodation spaces, apart from those provided in the poop and forecastle, should be concentrated around and over the engine-room spaces, thus leaving the remainder of the deck as free as possible from obstructions to cargo-handling. Each cargo hold should have hatchways as near as possible the same areas as the holds themselves. Unstayed samson posts should be fitted between each pair of holds, and the cargo winches should be mounted on a platform in an awthartship line with the samson posts. The author considers that a ship designed in this way would be able to load and

unload more quickly, and it is also considered that attention might be drawn to the greater use of doors, in the sides of the ship, for the purpose of loading and unloading.

STRUCTURAL STRENGTH AND WELDING

Structural problems still continue to confront shipbuilders and research into the problem of producing more efficient structures is a matter of great importance.

The increasing size of vessels of certain types, and particularly oil-tankers, has brought about considerable interest in calculations for the longitudinal strength of ships. Such calculations, which were rarely, if ever, carried out for merchant ships, have now become almost drawing-office routine. Therefore, a paper on a simplified method of calculating bending moments is obviously most welcome, and such a contribution came to us from South America. Professor A. Mandelli, of the Argentine Naval Academy, has written a paper on this subject, and although this was published by the Institution of Engineers and Shipbuilders in Scotland late in 1955, it does not seem out of place to refer to it in the present article.

The paper describes how it is possible, for any given condition of loading of a ship, to calculate, exactly, the bending moment amidships, without resorting to bending-moment curves. The determination of the influence line of bending moment amidships is also dealt with, and it is demonstrated how the complete bending-moment curve can be obtained readily, when required.

One of the difficulties in the reduction of the strength of ships to calculation is the correct assessment of the sea-going conditions the ship is likely to experience in service, *i.e.*, the height and length of waves which may be expected on any particular route. Much useful information on this subject has been collected during the past 10 years or so, and the latest addition to the literature on the subject came from America in the form of a paper by Mr. Norman H. Jasper, entitled "Statistical Distribution Patterns of Ocean Waves and of Wave-induced Ship Stresses and Motions with Engineering Applications," read before the American Society of Naval Architects and Marine Engineers in November last.

The author states that little is known about the frequency of occurrence of the various magnitudes of ocean waves, and that the object of the research described in the paper is to show how, by the use of statistical methods, it is possible to describe and predict service conditions for ships. For this purpose, wave observations taken continuously over a period of six years were studied. These were obtained from various weather stations in the Atlantic Ocean. Also, wave-induced motions and stresses obtained under a variety of operating conditions were studied for seven different ships. The analysis of the vast amount of data collected in this way showed that it was possible to approximate the probable distributions of wave height, wave length, wave induced pitch, roll and heave, and wave-induced ship stresses in a fairly simple manner. It is evident that research of this type will lead to a better understanding of the conditions to which ships are subjected at sea, and thus enable a more accurate estimate of the forces and moments on the structure to be made, and so, ultimately, to produce more economical structures.

A problem still of importance in the shipbuilding industry is that of brittle fracture in steel plates. Much research has been carried out on this subject since the war, and it would be dangerous to say that the difficulties have been solved completely. A survey of the brittle fracture problem has been made recently by Mrs. C. F. Tipper in a paper entitled "The Brittle Fracture Problem, 1943-56," read before the Institute of Welding in November last, and which is to be found in the *British Welding Journal* for October, 1956. The survey covers the period from 1943 to 1956, and gives a historical review of the problem. Such matters as crack initiation and propagation are dealt with, and criteria in impact tests are described. A number of references are given, and these should prove of great value to those interested in this important problem.

Brittle fracture has also been dealt with in a paper to the Institution of Naval Architects in the spring of 1956. The author of this paper, entitled "The Brittle Fracture Strengths of Welded Steel Plates," is Mr. A. A. Wells, and he gives an account of tensile tests on wide mild-steel plates of 1-in. thickness, where the plates contained central notched butt welds parallel to the direction of pull. The notches were made by fine saw-cuts in the plate edges, prepared for welding, and were intended to simulate weld flaws. The tests were conducted within the temperature range ±15° C. It was found that, at temperatures above 4° C, the plates sustained yield-point average static tensile stresses, before brittle fracture occurred. Below 4° C, brittle fracture across the weld residual-stress zones started from the saw-cuts, either spontaneously after welding or with small external loads. At 4° C, a single-stage fracture was produced at half the yield-point stress. It was found that, in welded plates which had been stress-relieved by stretching, no residual-stress zone fractures could be produced at less than the yield stress in the temperature range ±15° C.

Considerable importance was attached to the critical temperature at which alone complete fractures could be obtained at half the yield-point stress. The Charpy V-notch energy, of 7ft. lb at this temperature, matches the energy range identified for casualties in American welded ships. It would appear that the behavior in these tests could be explained in terms of the mechanical effects of weld shrinkage and residual stresses, and metallurgical damage over the narrow weld-hardened zone.

Allied to the problem of brittle fracture is the question of the quality and properties of the plate material being welded. A paper entitled "The Modern Manufacture of Steel Plate for Shipbuilding," was read in

January by Mr. T. F. Pearson before the North-East Coast Institution of Engineers and Shipbuilders. The author of this paper describes the complete steel production processes, including both acid and basic processes, and the question of refining in the open-hearth furnace. The rolling and finishing operations are explained, and the mechanical testing of the finished product is dealt with. The chemical, physical and metallurgical properties of steel are discussed.

Naturally, a most important subject dealt with in the paper is that of brittle fracture, and the author considers the development of improved steels for use in shipbuilding where welding is to be employed. The contribution which the steelmaker has made, in recent years, towards the brittle-fracture problem is to produce steels which are less susceptible to notch brittleness, or, in other words, the transition range has been displaced towards lower temperatures. It is of interest to summarize some of the ways in which these improvements have been effected. It will be remembered that one of the interim measures for improving the notch toughness of ordinary mild steel was to ensure that the manganese-carbon ratio was not less than 2½ : 1. The next development was the production of a still higher manganese-content steel, *viz.*, up to 1 per cent manganese. The effect of this was to increase the tensile strength, and, in order to keep the strength in the 28/32-ton range, it was necessary to reduce the carbon content. This type of steel was introduced in 1950. It is known that normalizing improves the grain structure, and thus improves the notch toughness, so that this process can be used with advantage.

Another method is to grain-refine the steel at tapping by the addition of aluminum. At the present time, the best results can be obtained with a Mn/C ratio of 8 : 1, the steel being grain-refined and normalized. Naturally, these improvements in properties, involving as they do the addition of more manganese and the employment of additional processes, cannot be achieved without extra cost. If, therefore, the high quality obtainable by these means is necessary in practice, the shipbuilder, and ultimately the shipowner, must be prepared to face the higher costs of such improved steels.

Another useful contribution to the brittle-fracture problem is to be found in a further paper, read by Mr. T. M. Norén before the North-East Coast Institution of Engineers and Shipbuilders, in November last, and entitled "The Nominal Cleavage Strength of Steel and its Importance for Welded Structures." The nominal cleavage strength is defined as the highest nominal tensile stress which a steel can withstand in the presence of a crack, without the initiation of fracture at the crack point. The nominal cleavage strength decreases continuously as the temperature decreases, just as the yield point increases with decreasing temperature.

If curves of these two strengths are drawn, the point of intersection would appear to be a transition temperature for the steel, defined as the temperature above which plastic deformation can take place in a large volume of material, despite the presence of a crack, but below which only minor local plastic deformation is possible immediately in front of the crack. It is stated that results have been obtained which showed a certain correlation to the results of impact tests as well as to those of other brittle fracture tests. The paper indicates that the quality of a steel with regard to its brittle-fracture tendency cannot be expressed simply by an impact transition temperature.

Turning now from the brittle-fracture problem, we come to the question of structural design, and mention may be made of the symposium on "The Plastic Theory of Structures," to be found in the *British Welding Journal* for August, 1956. The great pioneer of the plastic theory in this country is Professor J. F. Baker, of Cambridge University, and structural designers will be familiar with his work in this field. It is fairly safe to say that, in so far as ship structures are concerned, they are not designed with any such theory in mind. It has, however, been shown that where such a method of design has been adopted, greater economy in the use of material has been achieved. It is for this reason that the designer of ships' structures would do well to give this method of design serious thought in these days of high costs and shortage of steel. It would seem that the designer might well consider the transverse structure of a ship with its many redundancies from this point of view. The symposium deals with single and multi-storeyed framed foundations, thermal stresses, impact, frame instability and various design problems.

An interesting account of the testing of welding for warship construction is to be found in the *British Welding Journal* for October, 1956. The author of this paper—"Testing of Welding for Warship Construction"—is Mr. W. R. Seward, R.C.N.C. A description is included of the testing of welding at the Naval Construction Research Establishment, Dunfermline. The results of explosive tests are first discussed, and a brief account of the main findings of these experiments is, perhaps, fitting. Firstly, it may be stated that the resistance to explosive loading of the best submerged arc-welded plate was about 60 per cent of the plain plate. This efficiency was raised to 67 per cent when the plate was normalized at 900° C, after welding. Secondly, the strength of the best normally welded plate was about 40 per cent of that of the plain plate, and this was increased to 47 per cent by normalizing. It is interesting to note that, in the submerged-arc process, the welded plates were consistently stronger when the final pass was facing the charge, and also that, in the case of normally welded plates, greater strength was obtained when the weld force faced the charge. The results of a large number of tests on steels of different chemical compositions, and using different cooling rates, are discussed in detail. This paper will well repay study by the shipbuilder, as the information given of the weldability of different types of steel is of great value.

Turning to a purely theoretical consideration, men-

tion might be made of a short paper by Mr. W. Muckle entitled "Stresses in the Neighborhood of Discontinuities," which was presented to the North-East Coast Institution of Engineers and Shipbuilders, in November last. This paper draws an analogy between a stressed plate and the deflection of a plate bent by edge couples. It shows how, by considering the deflection of a plate, the stress distribution in a plate of the same shape might be obtained. It is intended that this method of obtaining stress distribution should be applied to plates where there are discontinuities, such as holes. No experimental technique is described in the paper, but, clearly, it is necessary to be able to measure accurately the deflection of the bent plate, and also the radius of curvature at various points, in order to apply the method.

In concluding this section on structural strength, reference is made to the work carried out by the British Shipbuilding Research Association. This work may be summarized under the heading of the determination of loads, stresses and deflections in ships' structures. A good deal of work has been carried out at the Imperial College of Science and Technology, London. Up to the present, pilot tests have been undertaken, to study the behavior of celluloid in small models. These tests are in preparation for a series of celluloid model tests on transverse strength, which are to be carried out at the College.

Two reports have been issued to member firms describing structural investigations on box girders, carried out at the College. In passing, it might be mentioned that some of this work was described in a paper given before the Institution of Engineers and Shipbuilders in Scotland, late in 1955. The first report, referred to in the foregoing, dealt with experiments carried out on a stiffened box girder, subjected to both bending moment and shearing force. The second report described the behavior of a stiffened box girder under pure bending, after the addition of longitudinal stiffeners to the compression flange.

There have been preliminary tests at the experiment tank of Messrs. Vickers-Armstrongs, Ltd., at St. Albans, on the determination of maximum bending moments due to waves. The staff of the Association have also been carrying out static bending tests on a number of ships. In addition, autographic recording and statistical strain gauges have been placed on a number of ships, and the records obtained are being analyzed.

As can be imagined, the work referred to in this brief summary is considerable, and the results will be awaited with great interest.

RESISTANCE AND PROPULSION.

The best indication of the progress being made in this branch of naval architecture in Britain is by referring to the research work which is on hand for the British Shipbuilding Research Association, and the work which is being undertaken by the Ship Division of the National Physical Laboratory. It is difficult to dissociate these two organizations in this field, since some of the B.S.R.A. work is being carried out at the N.P.L.

The B.S.R.A. have a program of propeller scale-effect tests in hand, and, for some time now, the staff of the Association have been studying problems in connection with this subject. For example, tests are being carried out at the National Physical Laboratory, in the compressed-air tunnel, on a number of cambered aerofoil sections. Another project for the B.S.R.A., under investigation at the N.P.L., is the detection of laminar flow on a 10-in. diameter model propeller. The tests on this propeller have been carried out with, and without, trip wires on the face and the back of the blades.

During 1956, the B.S.R.A. issued a report to member firms describing experiments on propeller scale-effect undertaken at the testing tank of Messrs. John Brown and Co. (Clydebank), Ltd. In these experiments, a 24-in. diameter propeller was tested with trip wires attached.

A most important aspect of the B.S.R.A. work on resistance and propulsion is the study of ship performance, both on trial and in service. The B.S.R.A. staff have attended a number of ship trials during the past year and valuable information has been collected. In addition, at the Association's laboratory at Sunderland, automatic recording instruments for measuring the performance of ships in service have been developed, and many of these instruments are now in use.

A report issued during the past year described experiments to determine the influence of surface roughness on the performance of a model propeller.

The work of the Ship Division of the National Physical Laboratory is, as usual, divided between commercial testing of models and propellers for shipowners and builders, and fundamental research work. With regard to work in the former category, the fact that a delay of five or six months exists in putting resistance and propulsion tests in hand for shipbuilders, is indicative of the importance which is now placed in the tank test for new ships. In the year up to September, 1956, no fewer than 50 special investigations were carried out, and these included two passenger liners, 21 cargo ships, seven oil-tank vessels, three coasting motorships, six trawlers and two tugs.

In the field of research, no fewer than 32 models were made, of which 15 were for the B.S.R.A. and five for the ship-model correlation comparison of a number of ships. An important fact which has emerged in the consideration of ship-model correlation is that hull roughness is probably the major factor accounting for differences between model and ship. Special tests are being carried out in conjunction with the B.S.R.A. on the D.S.I.R. ship *Sir William Hardy,* both in the foul and clean conditions.

Investigations of the influence of form factor on frictional resistance are being pursued, and among the other special items are studies of the acoustic

radiation from cavitation, behavior of lightships and pitch damping factors.

Substantial progress has been made with the N.P.L. Ship Hydrodynamics Laboratory at Feltham. The whole project is expected to be completed by the beginning of 1959, and, when this is ready, the facilities of the Ship Division will be very greatly extended.

More detailed accounts of some of the research by the British Shipbuilding Research Association and the National Physical Laboratory are given in the following notes, where various papers emanating from these establishments are discussed.

A matter still of great importance in the accurate prediction of ship resistance is the correct assessment of skin friction resistance. We have to record two papers which have been published during the year on this subject. The first to which reference is made is "The Viscous Resistance of Surface Vessels and the Skin Friction of Flat Plates," by Mr. P. S. Granville, and read before the American Society of Naval Architects and Marine Engineers in November last. This paper first of all reviews the viscous resistance of ship forms in connection with the prediction of the full-scale resistance of ships from the results of model tests. The author has derived a general formula for the resistance of flat plates from the similarity laws, and this provides a common basis for the form of the Schoenherr, the Lap-Troost and the Hughes formulae. A consideration of experimental results has led to the conclusion that the basic Froude hypothesis concerning the separation of viscous and wave-making resistances is justified; but to enable accurate extrapolations to full-scale resistance to be made, a full-scale ship with a hydrodynamically smooth surface must be tested. It would seem, too, that further research into the influence of basin-wall effect on large models, and turbulence stimulation on small models, is required. The author is of the view that the use of a flat plate line, as a reference line for form or viscous resistance, still seems a fruitful method of inquiry. The concept of the form, or viscous resistance coefficient, having a fixed part, and a part proportional to the flat plate resistance coefficient, is inclusive enough to encompass any probable variations.

Another valuable contribution to the ship frictional-resistance problem came from Mr. G. Hughes in a paper on "Viscous and Interference Effects Deduced from N.S.M.B. and N.P.L. 'Victory'-model Tests," read before the Institution of Naval Architects at their spring meetings. In this paper, Dr. Hughes discusses viscous and interference effects as deduced from the "Victory"-model tests of the Netherland Ship Model Basis and of the National Physical Laboratory. The combined results from these two establishments have been analyzed by the author in relation to assumed viscous formulae, and the tank-boundary interference effects, required to provide a balance, have been deduced. It is demonstrated that the interference effects, which correspond to the viscous formulae proposed by the author from previous work, are consistent and reasonable, but further work of a similar nature is required to enable the viscous and interference effects to be separated out more accurately. One of the very valuable points about this paper is that it contains a great many results of experiments on resistance with the actual measurements. This should prove very useful to the research worker, as he is thus enabled to re-analyze the data in his own way, if he so wishes.

Some research work of the National Physical Laboratory has been made available in a paper by Mr. J. F. Allan and Mr. R. S. Cutland, entitled "The Effect of Roughness on Ship Resistance," read before the North-East Coast Institution of Engineers and Shipbuilders. This paper deals with the effect of hull roughness on resistance, and includes the effect of structural roughness on all-riveted and all-welded shells and of paints and other local roughnesses which frequently occur. The smooth-surface resistances, with which the roughness experiments were compared, were the results of experiments on pontoons 15ft. long, 4ft. wide and 0.3in. draft. The roughnesses tested were transverse plate edges facing aft and forward, and also filled in with Plasticene to give a one-in-four taper; rivet points on transverse plate edges; transverse welding beads; frame rivets; fore and aft seams; and paint roughness. The speed of the water in the boundary layer was measured for all these tests. The results of the tests were presented in the usual form of C_f to a base of Reynolds number.

When the results of the tests are compared with the smooth-ship Schoenherr resistance, the amount of power being wasted in a riveted ship, due to this cause, is very considerable. The increase in resistance over the smooth values for various types of ship may be summarized as given in Table I.

TABLE I.

Vessel	Riveted, per cent	Welded, per cent
Tug	6.2	0.6
Trawler	11.6	1.2
Collier	14.5	1.3
Coaster	13.5	1.2
Cargo ship	15.4	1.4
Tanker	24.9	1.6
Liner	[26.8 [37.3	1.6] 1.7]

The most important single item accounting for the increase in resistance due to structural roughness is the transverse plate edge. This accounts for nearly half the total increase in resistance. The reduction in this structural resistance for the welded ship is quite remarkable, and if this investigation did nothing more than demonstrate the vast superiority of the welded ship over the riveted ship, from a propulsion point of view, it would be invaluable. However, there is much more of value in the paper which will well repay careful study.

The Taylor Model Basin Series 60 Models must now be very well-known to naval architects. A fur-

ther paper giving additional information on these models has been contributed to the American Society of Naval Architects and Marine Engineers by Mr. F. H. Hodd and Mr. P. C. Pien. The paper is entitled "Series 60—the Effect upon Resistance and Power of Variation in L.C.B. Position," and in it is discussed the influence of the position of the longitudinal center of buoyancy on the resistance. The position of the L.C.B. has, of course, long been recognized as a measure of the relative fullness of the two ends of the form—hence its effect on the resistance. At each of the block coefficients of the five parents of the series, covering a range from 0.60 to 0.80, new models have been tested in which L.C.B. was varied. The models were tested both for resistance and propulsion. A large amount of data obtained from these tests are available in the paper under discussion, and it is not proposed to comment upon it in detail here. It is sufficient to say that the results provide a valuable guide to designers in deciding the longitudinal distribution of displacement in forms in the range of fullness covered. From the results of these experiments, the new basic models have been chosen for the final part of this important research, which is to consist of geometrical variations of both the length/-breadth ratio and the breadth/draft ratio.

In recent years, a factor which has emerged in the tank-testing of ship models is the influence of the results of the model size in relation to the size of tank in which the tests are carried out. It would be too much to say that this problem is solved completely, and, therefore, a welcome addition to the literature on the subject is by Mr. G. Hughes. This appeared as a paper to the Institution of Naval Architects during the past year, under the title of "The Effect of Model and Tank Size in Two Series of Resistance Tests." In this work, after a discussion of the problem in general terms, a method is developed for determining viscous and blockage effect in resistance tests carried out on geometrically similar models in more than one tank. The method proposed by Dr. Hughes is applied to the results for a fast steamship and for a cruiser. These experiments were carried out originally at the Hamburg Model Experiment Establishment and they were supplemented by work at the National Physical Laboratory. If the increase in total resistance coefficient could be expressed as $\triangle C_t = k\ (a/A)^n$ where a/A is the ratio of the maximum immersed area of the model to the cross-section area of the tank, the author says that it is not possible to determine, with certainty, the value of k and n from the experiments analyzed. It is certain that k increases rapidly with Froude number, and that n might be expressed as a function of the frictional and wave-making coefficient ${}_vC_T$ and ${}_wC_T$ with the influence of ${}_wC_T$ predominating. The analysis in this paper extends our knowledge of a most important aspect of tank testing work, and carries us a stage further towards the accurate prediction of this effect.

Reference is next made to two papers dealing with special types of craft, *viz.*, trawlers and coasters. The first of these—"The Resistance of Trawler Hull Forms of 0.65 Prismatic Coefficient"—is by Mr. Cedric Ridgeley-Nevitt, and is found in the Transactions of the American Society of Naval Architects and Marine Engineers. The paper covers the development of a fishing-trawler hull of 0.65 prismatic coefficient and displacement-length ratio of 300, to serve as a parent form for future resistance experiments. An average American trawler was designed and tested. Three variations covering the effects of water-plane coefficient, midship-section coefficient and shape of section-area curve were investigated to find desirable values from a smooth water resistance standpoint, and the indicated changes were incorporated into two new hull designs. The better of these two forms proved to have almost 12 per cent less resistance than the first form tried. These forms are particularly susceptible to laminar flow and, therefore, an extensive investigation of the turbulence stimulation problem, became necessary. The investigation showed that, with the major parameters of displacement-length ratio and prismatic coefficient fixed, it is possible to design hull forms with wide variations in resistance. A significant point is that small changes in form can result in appreciable changes in resistance, and it is concluded that there is still a very major element of art in designing a hull with minimum resistance.

The other contribution referred to is by Mr. J. Dawson and is on "Resistance and Propulsion of Single-screw Coasters; Part III.—L/B=6½." This paper was read before the Institution of Engineers and Shipbuilders in Scotland, and represents Part III of a research carried out at the National Physical Laboratory on single-screw coasters. The present series is on ships with a ratio of length to breadth of 6½. There were 12 models tested in all, the parent forms having block coefficients of 0.75, 0.70 and 0.65 at the load draft. For each value of the block coefficient, three other models were made, having different positions of the longitudinal center of buoyancy. All models were tested at the deep load, medium load and ballast drafts on an even keel. Tests were also carried out in the ballast condition with a trim of 5ft. by the stern. Propulsion experiments were undertaken, in addition to the ordinary resistance tests. One interesting feature may be quoted from these experiments, *viz.*, that the optimum position of L.C.B. differs when considered from the point of view of ©, Q.P.C. or ©/Q.P.C. This can best be shown by quoting the actual results for the three values of the block coefficient. These are given in Table II.

TABLE II.

C_B	$V/\sqrt{L}$	Optimum Position of L.C.B. per cent L.		
		For ©	For Q.P.C.	For©/Q.P.C.
0.75	0.66	1.00F	0.70F	0.90F
0.70	0.76	1.03F	0.63F	0.85F
0.65	0.86	1.60A	1.74A	1.68A

It will be noted that the differences between the results for © and ©/Q.P.C. are not very large, being from about 0.1 to 0.2 per cent of the length of the ship.

Another valuable series of resistance and propulsion experiments has been carried out in Sweden at the Swedish State Shipbuilding Experiment Tank. The results of these tests have been published in "Experiments with Tanker Models," read before the North-East Coast Institution of Engineers and Shipbuilders by Mr. Hans Edstrand. The parent form chosen for this series of experiments was that a tanker of about 22,000 tons displacement and having a speed of about 15 knots. The shape of the fore-body sections, the length/breadth ratio and the breadth/draft ratio were the first variables to be considered. The tests on the shape of the fore-body indicate that sections of U-form are generally superior to those of V-form. The length/breadth ratio appears to influence performance only to a limited degree, while an increase in the breadth/draft ratio causes an increase in resistance, but, on the other hand, it produces an improvement in propulsive efficiency. The breadth/draft ratio variation enabled the investigation to be extended to forms suitable for large tankers of about 40,000 tons displacement. The form with the higher breadth/draft ratio was used as the parent form for a series involving variation of the block coefficient. The effect of varying the longitudinal position of the center of buoyancy was also investigated. Very full information is available in this paper for the ship forms tested, and also a great amount of experimental data are to be found for the various tests carried out, and this should be of great value to the tanker designer.

A subject about which little is heard is the testing of yacht forms, and the paper on "Yacht Testing" presented to the Institution of Naval Architects by Mr. J. F. Allan, Mr. D. J. Doust and Mr. B. E. Ware, will therefore be of great interest. The paper is concerned with the sailing yacht, and after reviewing the techniques used previously in carrying out experiments on this class of craft, a description of the N.P.L. dynamometer is given. The models used for work on yachts are made of wood, and they are arranged to have an overall length of about 5 ft. An interesting point in connection with model manufacture is that the center of gravity must be in the correct scaled-down position corresponding to that of the full-scale prototype. A most important factor in the tests of these models is the stimulation of turbulence, and, for this purpose, studs ⅛ in. in diameter are fitted below the water-line in the forebody. These project 1/16 in. from the hull and are spaced in a set pattern. Investigation of the turbulence produced by this means showed that, at speeds above 2 ft. per second, satisfactory turbulence stimulation was produced. While the apparatus described in this paper enables a great deal to be learned on the subject of yachts, it is clear that a great deal of research work still remains to be done before the performance of these vessels can be understood completely. It is considered by the authors, for example, that further investigations on sail forces, hull design, stability, center of effort and design of appendages would yield valuable results.

Another somewhat unusual subject, which has been dealt with during the year, is the performance of a high-speed launch. The information on this subject is to be found in a paper entitled "The Planing Performance, Pressures and Stresses in a High-speed Launch," read by Commander Peter Du Cane, R.N. (Rtd.), before the Institution of Naval Architects. This describes the results of tests on a 68-ft. launch of the hard-chine type, designed and constructed primarily for air/sea rescue purposes. While we are concerned, here, with the hydrodynamic features of this vessel, it might be noted that the hull of the ship was constructed of aluminum, and welded throughout. The side panels of the hull consisted of a fiber-glass laminate, molded to shape. The speed of the launch was in excess of 40 knots, and, in order to establish the suitability of the craft for service conditions, recorded measurements were made of planing pressures, accelerations and stresses in the planing bottom. As an indication of the conditions to which vessels of this type are subjected, it might be noted that the maximum acceleration at the wheel position was 6 g, while this went up to nearly 8½ g in the fore peak. The maximum panel pressure was 12.3 lb per sq. in. The propulsion characteristics of these high-speed vessels are of interest, and, in the present craft, a propulsive efficiency of 0.53 was obtained, which was considered quite good. The propeller blades have hollow sections and they were tested at appropriate shaft angles in a cavitation tunnel. The tests were carried out over a wide range of cavitation number values and of advance coefficient J. Despite some 400 hours of mostly high-speed running, the amount of erosion on the blades is negligible. It is considered that this may indicate a fully cavitating blade back.

We have had occasion to refer, previously, to work on the subject of paddle wheels, carried out at the Dumbarton Experiment Tank. The second part of this research work appeared during the course of the year, the results being presented to the Institution of Engineers and Shipbuilders in Scotland by Mr. H. Volpich and Mr. I. C. Bridge, in a paper entitled "Paddle Wheels; Part II.—Systematic Model Experiments." The earlier experiments to which reference has been made showed no conclusive effect in terms of size, and, in carrying out these further tests, it was considered reasonable to make them on the larger of the wheels only. The experiments cover a wide range of variables, including size, number and shape of floats, immersion of floats and the position of the star center. The results of these experiments are presented in the form of charts in terms of a speed parameter $V_a\sqrt{D}$, a revolution-per-minute parameter $N\sqrt{D}$, and thrust and power parameters represented by $T/\rho D^3$ and 100 d.h.p./$\rho D^{3.5}$, respectively. This work, together with that published earlier, represents a valuable contribution to the paddle-wheel

problem, and the results should prove exceedingly useful to designers who have to deal with ships which employ this means of propulsion.

Contra-rotating propellers are not new, but they have, perhaps, been somewhat neglected in the past from the purely scientific point of view. Some Dutch work on this subject is therefore welcome, and is to be found in the Transactions of the Institution of Naval Architects. The paper was given at the spring meetings of the Institution by Dr. J. D. van Manen and Dipl. Ing. A. Sentic, and was entitled "Contra-rotating Propellers." The experimental work described was on a series of systematically-varied contra-rotating propellers. The front propellers, which were of the B 3-65 series, had pitch ratios varying from 0.6 to 1.4. The rear propellers were also of the B. series, but their diameter-pitch ratios and blade-area ratios were determined by calculations based on the circulation theory for ship propellers. The pitch ratios of these propellers varied from 0.928 to 1.492, while the blade-area ratio varied from 0.667 to 0.714. The constant diameter of the front propeller was 240 mm. while the diameters of the rear propellers varied from 230.5 to 240 mm. There was a constant distance of 0.37 D between the propellers. The results of the propeller tests were plotted in the form of $B_{p-\delta}$ charts. The experiments showed that the contra-rotating propeller system is one of high efficiency, and this is a factor worth considering in developing special propeller arrangements. From the data obtained in the experiments, it has been found possible, with the aid of the circulation theory, to develop a method whereby contra-rotating propellers may be designed very rapidly. The testing of contra-rotating propellers in the cavitation tunnel is recommended, since the results of such tests will give valuable data concerning the quality of the design. It would seem that this series of experiments has put the design of this special type of propeller on a sound basis, and should enable the designer to assess the real value of this somewhat unusual method of propulsion.

The design of propellers to suit the wake conditions in which they are to operate has received much attention in recent years, and the latest contribution to this subject is to be found in a paper by Mr. Laurens Troost, on "The Pitch Distribution of Wake Adapted Marine Propellers," read before the American Society of Naval Architects and Marine Engineers. The paper is a theoretical one, and in it, the author continues the development of the ideas which he put forward in an earlier publication. The relations between thrust deduction and wake factors are developed in terms of propeller loading, and it is shown how these relations can be integrated over the propeller radius to obtain a solution of the problem of the radial distribution of thrust deduction, as a function of the radial wake distribution and propeller loading for propellers of minimum energy loss. The investigation shows that the pitch distribution for a wake-adapted screw may be given by $\frac{P}{P_o} = 1 + \frac{1}{2} e_i \left(\frac{1-w^1}{1-w} - 1 \right)$. This equation gives a pitch distribution which is in conformity with good practice, and it may be used to improve the efficiency of screws designed from methodical series.

In concluding this section on resistance and propulsion, attention is drawn to research work carried out in Holland on the subject of model and ship trials in shallow water. This work was published in the form of a paper to the American Society of Naval Architects and Marine Engineers by Dr. J. D. van Manen and Professor W. P. A. van Lammeren, entitled "Model and Ship Trials in Shallow Water." The work has involved an exhaustive series of tests, in the towing tank, on the subject of wall and shallow-water effects. The wall-effect tests have employed the method of images, that is, two or more geometrically similar models have been towed abreast. The model experiments have been related to full-scale tests in the Rhine and in a lake. It has been possible, among other things, to divide the wall effect into two parts —one concerned with frictional resistance and the other affecting wave-making resistance.

STABILITY, OSCILLATIONS AND VIBRATION.

In the field of stability, we are able to report an important paper given to the Institution of Naval Architects by Mr. H. E. Steel and entitled "The Practical Approach to Stability of Ships." Mr. Steel discusses the historical aspect of stability, and he deals with various casualties which have been attributed to deficiency in stability. Another important aspect of the problem is that of capsizing during fire-fighting, while in port, and recommendations are given with a view to avoiding this occurrence. Concerning stability criteria, the author states that the practice in passenger ships of allowing small metacentric height for the purpose of easy rolling in a seaway has now vanished. This has been brought about by the requirements of stability in the damaged condition. The fact that a ship must be stable after flooding necessitates a considerable margin of stability in the intact condition. Another factor which is important is that a considerable reduction in metacentric height can take place between departure and arrival conditions, because of the fact that fuel is burnt out at a low center of gravity in the ship. For home-trade and coasting vessels, Mr. Steel considers that the stability would be adequate if the righting lever GZ was approximately 1ft. at 30 to 45 degrees inclination, associated with a metacentric height of about 18in.

Another matter related to stability is the rolling and pitching of a ship, and a useful contribution to this problem has been made by Mr. D. E. Cartwright and Mr. L. J. Rydill in their paper on "The Rolling and Pitching of a Ship at Sea—a Direct Comparison between Calculated and Recorded Motions of a Ship in Sea Waves," read before the Institution of Naval Architects. The motion of the R.R.S. *Discovery II* was recorded at sea, and, at the same time, records were

taken of the waves encountered by means of a ship-borne wave recorder. These observations were made when the ship was steaming at about 6½ knots on a series of courses in long-crested waves. The method adopted for analyzing the results was by means of spectral analysis, using an automatic Fourier analyzer. The observed results are compared with theoretical results, and it is noted that the observed results are quite close to, and never far from, those derived from theory. The causes of most of the differences are attributed to statistical variations, but there are some cases where this would not account for the difference. Such cases are pitching with waves near the beam and the response on either side of synchronism in rolling where there is a significant difference between theory and experiment. It is of interest to note that the comparison between the "simple" and "advanced" methods for calculating the ship's response appears to show that the improvement with the latter, though real, is not very great, and probably does not justify the extra labor involved.

Another paper, delivered at the same time, gives an account of a ship-borne wave recorder, which has been used in the *Discovery II*. The principle of this wave recorder is that it measures the height of the wave relative to some fixed point on the ship's hull and adds this to the height of the point relative to an imaginary reference surface, thus giving the height of the water surface independent of the position of the ship. The first of these quantities is measured by calculating the pressure on the hull of the ship; while the latter, which is more difficult to deal with, is determined by measuring the vertical component of acceleration, and integrating twice. An instrument of this type has now been in service for more than two years, and several thousands of records have been taken.

Vibration in twin-screw turbine-driven ships has been considered by Mr. J. W. Ramsay in a paper to the Institution of Naval Architects, entitled "Aspects of Ship Vibration Induced by Twin Propellers." The character of the vibration in these vessels depends partly on the magnitude and frequency of the forces imposed upon the hull by the propellers, according to their geometry and location, and partly upon the elastic properties of the hull structure. Vertical vibration is generated by harmonic-pressure forces on the underside of the hull, while mixed wake forces induce transverse vibration. It is believed that hull-pressure forces can be estimated with reasonable accuracy by means of model experiments and theoretical analysis. The elastic response of the hull girder conforms to the principles upon which most methods of calculating hull frequency are based. It is believed that the first five or six natural frequencies of vertical flexural vibration can be calculated as accurately as the estimates of hull strength and entrained water allow. In the type of vessels being discussed, vibration is only significant at the stern, and, in the absence of local flexibilities, will remain approximately constant at all speeds.

MISCELLANEOUS TOPICS

The ever-present problem of corrosion in the structures of ships has received attention during the past year. Mr. H. J. Adams and Mr. J. C. Hudson have discussed this subject at a joint meeting of the Institution of Naval Architects and Institute of Marine Engineers. This paper contains a vast amount of data on this very important subject, and it has all the experience of Lloyd's Register of Shipping behind it. We would refer those interested in this particular problem to the original paper—"The Corrosion of Cargo Ships and its Prevention"—which contains too many aspects of the subject for any brief survey to be made here.

Another contribution to the corrosion problem has been made by Mr. R. P. Graham, Mr. F. E. Cook and Mr. H. S. Preiser in a paper to the American Society of Naval Architects and Marine Engineers, entitled "Cathodic Protection in the U.S. Navy; Research—Development—Design." This is a very comprehensive discussion of this most important problem. Cathodic protection has received a great deal of attention in recent years and a large amount of research work has been carried out by the Bureau of Ships. It is expected, according to the outlines of this paper, that rapid strides in the improvement of materials and equipment will result in reliable performance with a minimum of normal operation and maintenance. It is believed that, in the future, cathodic protection will become integral with ship design.

The mechanization of fishing vessels has been discussed by Mr. W. Lochridge in a paper to the Institution of Engineers and Shipbuilders in Scotland. This paper, as indicated by its title ("Mechanization in Fishing Vessels"), describes the machinery used for processing fish in several modern types of fishing vessel, and an account is also given of mid-water trawling experiments.

We make brief reference to a paper on a totally different subject, *viz.*, the use of the analogue computer. Mr. J. R. Hunter in his paper on "Shipyard Use of the Analogue Computer," to the Society of Naval Architects and Marine Engineers, describes how this instrument may be applied to the solution of the engineering problems encountered in shipbuilding, and he discusses the general considerations which should govern the type of instrument selected for shipyard purposes. Undoubtedly, an instrument of this type, when thoroughly understood, could be of great service to the ship design office, where long and complicated calculations are quite common.

The British Shipbuilding Research Association have in hand further work on launching greases. This work is being carried out on models, and full-scale tests are also being made. The model tests are to be carried out at the Association's laboratory at Sunderland, the object being to determine the coefficient of starting friction for two greases.

Finally, we may mention the progress of two developments. The first is the Hydroconic system of

construction developed by Messrs. Burness, Kendall and Partners, Ltd. (now Burness, Corlett and Partners, Ltd.). Trawlers have been built on this system, and tank tests have shown reasonably good results. Other craft built on this principle include the cargo motorship *Lachinedoc* and the tug *Sydney Cove*.

The second development is in the use of fiber-glass as a material of construction. The development in the use of materials of this type for small boats has continued, and this is clearly a type of constructional material which may have great possibilities in the future.

The French Navy has recently ordered a helicopter carrier. It is conjectured that the ship will be capable of the functions of a base for ASW helicopters, a command vessel, or a troop transport. The ship displaces about 10,000 tons with a length of 590 feet and a beam of 78½ feet. Her speed is estimated at 26.5 knots.

* * * *

The phenomenal growth of tankers since the end of World War II has incubated recent discussions of even more astounding prospects. In a paper read before the King's College Society of Naval Arctitects, Mr. A. I. Livas has discussed the possibility of a 500,000 DWT ship, having a length of 1545 feet and a beam of 200 feet. The proposer estimates that 150,000 SHP would power such a ship at 24 knots.

"THE SHIP-BUILDER & MARINE ENGINE-BUILDER"

TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1956

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STEAM TURBINES AND BOILERS

THE coming into service of the twin-screw turbine-driven passenger and cargo steamship *Empress of Britain* once more aroused great interest in the gas-reheated steam cycle, and in a paper presented to the Institute of Marine Engineers in November, Mr. A. W. Davis described the development of this installation and quoted some service results. He also made a comparison with the performance of some earlier liners of the same fleet, and briefly indicated the possible future development of reheating. It had been recognized that in the turbo-electric *Beaver*-class cargo vessels (built in 1946), the electrical transmission losses rather more than offset the gain due to reheating and, early on in the design, it was decided to have a normal geared transmission, together with directly-reversible turbines. Because of the rejection of the non-reversible turbine and electric drive, the problem of providing an adequate protection for the reheating elements, during maneuvering, had to be faced. Damper control was not considered suitable, and it was decided to use a separately fired reheater and the fuel oil was arranged to pass through two spring-loaded valves, kept open by a steam supply in excess of 60 lb per sq. in., and connected, respectively, to the port and starboard h.p. turbine exhaust. Thus, shutting-down to stop or maneuver, on either engine, automatically put out the reheat boiler, if it had inadvertently been allowed to remain lit up. Combined steam isolating and by-pass valves were also arranged with a safety interlocking device, to ensure that the by-pass valve is opened first when by-passing, and is shut last on opening-up the reheater to steam.

By means of design studies, the most desirable steam conditions for the required 30,000 S.H.P. were indicated as 680 lb per sq. in. at 850° F, with reheat to 850° F. The requirements for astern power largely influenced the boiler size and two main boilers of Foster Wheeler controlled-superheat type were installed, each capable of a maximum output of 123,000 lb per hr.; whereas, under service steaming conditions, only 55 per cent of this output was required. The reheat boiler was designed to generate 58,000 lb per hr. of superheated steam and to reheat 167,000 lb per hr. from 610° F to 850° F. Auxiliary steam in port was provided by a Howden-Johnson boiler giving about 15,000 lb per hr. of saturated steam at 200 lb per sq. in. At sea, saturated steam was taken from the main drums at 680 lb per sq. in. and passed through the coils of a steam-to-steam generator, capable of supplying 12,000 lb per hr. of steam at 125 lb per sq. in. for fuel-oil heating, galleys, gland steam, evaporator, etc. Steam for the large air-conditioning units was bled-off from the main steam drums through an air-pressure controlled reducing valve.

The main feed system comprised four extraction pumps, two sets of air ejectors, two gland-ejector condensers, a drain cooler, a condensate circulated distiller and one feed heater. Steam was bled from the tenth stage of the i.-p. turbines for feed-heating and for air heating. Bled steam was also used for the evaporator, which was single-effect and capable of an output of 130 tons per day. There was an alternative steam supply from the main boiler and from the auxiliary boiler. The sea-water supply to the evaporator was treated with ferric chloride, to prevent scale formation.

During a special test run of 22 hours in good weather and with an hotel load less than normal, the all-purpose fuel-consumption rate was 0.537 lb per S.H.P. per hr., and the propulsion-only fuel-consumption rate was 0.495 lb per S.H.P. per hr. This latter figure includes power for all auxiliaries necessary for the main machinery and steering. The hull was five to six months out of dock. The author examined reasons for the small differences between these figures and the design figures, and said that the intended economy had been achieved and, as a result of ex-

perience with the installation, further saving in fuel consumption could be effected in a later installation.

The Babcock & Wilcox two-drum selectable superheat boiler is proving to be a very flexible and attractive steam-raiser. The gases flow across the tube bank in two parallel paths, separated by a baffle division of chrome ore packed in between tubes, and then through a set of baffles, which are so interlocked that movement of one lever controls the relative flow along each path. One path consists solely of generating tubes, and the other contains all the super-heating elements and some generator tubes, so that the degree of superheat can be controlled throughout the full designed range. The superheating elements can be protected during warming-up periods, and maximum superheat temperature can be approached in a controlled manner. The boiler will supply full output at the lowest superheat temperature, and thus, astern turbines can be designed for an operating temperature such as, say, 750° F. It can also supply both saturated steam and superheated steam in varying proportions. First developed for frigates of the Royal Navy, it has now been ordered by several British owners and its performance under Merchant Service conditions will be awaited with interest.

With installations using advanced steam conditions and having a large auxiliary load, it is necessary to control, carefully, both the auxiliary exhaust pressure and the boiler-feed temperature, in order to maintain the efficiency of the whole plant while varying the power and auxiliary steam-flow rates. Several vessels are now using pneumatically-operated control gear to maintain a steady back-pressure on turbine auxiliaries, while, at the same time, feed-heating is also controlled. Surplus exhaust steam is dumped into the main condenser, while, if the feed temperature drops, more steam for feed heating is drawn from either main engines or auxiliaries, or even, as a last resort, live steam from the boilers.

The machinery of the trawler *Braunschweig* is at the other end of the scale in comparison with the *Empress of Britain*. A single turbine having optimum efficiency at 1,000 S.H.P. is coupled, through double-reduction gearing, to an Escher-Wyss four-blade controllable-pitch propeller. The stop-valve steam conditions are 395 lb per sq. in. at 770° F, and the turbine speed is 8,000 r.p.m.; the reduction gearing gives a 40 to 1 reduction. An auxiliary turbine drives both a D.C. generator for the trawl winch and an A.C. alternator for the other auxiliaries and is in use while fishing; when the vessel is running free, electrical requirements are supplied by a 130-kVA. alternator, driven-off the propeller shaft and a stand-by Diesel alternator. The total specific fuel consumption (both main and auxiliary) is estimated to be 0.762 lb per S.H.P. per hr.

The shutting-down of steam plant in order to deal with comparatively small leaks is often inconvenient. A thermo-setting compound has been developed which can be injected against pressure, say, down a leaking bolt or between the flanges of a leaking joint. It hardens within a half-hour and is said to make a long lasting joint, and, in many circumstances, it provides a satisfactory stop gap repair.

DIESEL MACHINERY

The symposium of four papers on "Recent Developments in Marine Diesels," presented to the Institute of Marine Engineers, was of outstanding excellence; the separate papers were entitled as follows: —

"Turbo-charging of Burmeister and Wain Opposed Piston and Poppet-valve Engines," by Mr. H. Carstensen;

"Recent Developments in Marine Diesels (the Doxford Engine)," by Mr. P. Jackson;

"Some Aspects Concerning the Supercharging of Existing Two-stroke Marine Diesel Engines," by Mr. W. Kilchenmann; and

"Two-stroke Marine Diesel Engines with Uniflow Scavenging and Constant Gas-pressure Turbocharging," by Mr. F. G. Van Asperen, and Ir. H. Schultheiss.

All of the authors dealt with the problems of design and operation associated with turbo-charging two-stroke cycle engines and Mr. Kilchenmann gave a particularly full treatment of the problems, covering the pulse and constant-pressure systems, on the turbine side, together with parallel and series operation of a mechanically-driven scavenge pump.

Mr. F. G. Van Asperen voiced the generally agreed opinion that, as regards the pressure-charging system, no direct conclusion had been reached as to whether the pulse or the constant gas-pressure system would be preferred at higher-charging pressures. His own preference was for the constant-pressure system, whereas Mr. Kilchenmann preferred the pulse system.

In addition to the development of turbo-charging the Doxford engine, Mr. Jackson dealt with the development of a new injection system, where a crank-driven pump discharges fuel into an accumulator bottle at 6,000 to 7,000 lb per sq. in. and a small timing valve, operated by a cam, is lifted to permit the fuel to be sprayed by means of a typical jerk-pump fuel injector. There are a separate pump plunger, accumulator and timing valve for each cylinder—the metering of the fuel being done by the fuel pump and, as its name implies, the timing being controlled by the cam-operated valve. The system is small and compact, and operates with little noise. It has been found that the cam toe can be phased symmetrically relative to the inner dead-center of the engine, so that it will operate equally well in the ahead or the astern direction, without alteration. Thus, a new starting system was developed, so that the direction of rotation was governed by the position of the starting lever, which controls the order in which air is distributed to the cylinder. The symposium concludes with a comprehensive bibliography of articles on two-stroke turbo-charged marine Diesel-engine types.

A range of turbo-chargers, each consisting of a single-stage centrifugal compressor and single-stage

axial-flow exhaust-gas turbine, mounted on the same shaft, have been developed by the Brush Electrical Engineering Co., Ltd. Two types are already in production, one giving a gauge boost at sea-level of 9 lb per sq. in., and the other giving 15 lb per sq. in. Plain bearings are used, and the lubrication of the pressure-fed recirculating type is self-contained, making the unit mechanically independent of the engine. The turbine inlet is designed for a temperature of 1,200° F, there being arrangements incorporated to allow for differential expansion. Diagrams and performance curves were given in *Gas and Oil Power* for July, 1956.

The Fiat Company now join the ranks of those who have successfully developed a supercharged large two-stroke cycle engine with transverse scavenging. Turbo-blowers and engine-driven pumps were used together, both in series and parallel. Despite the greater simplicity of construction of the parallel arrangement, its less satisfactory behavior at low speed (due to the blower operating below its delivery speed) has led to the adoption of series arrangement of piston pumps and blowers.

Before the Second World War, the chief emphasis was on fuel economy for main machinery and, to a lesser degree, on weight and space occupied; but with changing economic conditions, the relative importance of fuel economy has been reduced, while the importance of maintenance costs continued to mount. High rates of cylinder wear contribute, to a large extent, to the maintenance costs of low-speed marine Diesel engines, and it is, therefore, unfortunate that the use of heavy fuel oil has often resulted in high rates of cylinder wear. This aspect was dealt with by Mr. M. J. van der Zijden and Mr. A. A. Kelly, in their paper on "Combating Cylinder Wear and Fouling in Large Low-speed Diesel Engines," read before the Institute of Marine Engineers early last year. It was pointed out that careful cleaning of the heavy fuel oil, while being essential, did not provide the whole solution; furthermore, experience has shown that the use of heavy duty oils for cylinder lubrication, while extremely efficacious for medium and high-speed engines, cannot sufficiently reduce the high rates of liner wear of slow-speed Diesel engines. An intensive study of the problem at the Shell laboratories showed that the need for having wear-reducing and anti-fouling additives, soluble in oil, severely limited the choice of possible additives. By breaking with this requirement and using water-soluble additives, to be carried by the oil in emulsification, it was found that much more effective wear-reducing lubricant could be obtained. The final outcome was an emulsion in which the waterphase is dispersed in the oil, having a viscosity of 1,100 secs. Redwood No. 1 at 100° F (bringing it into the S.A.E. 50 class), together with a stability of over 12 months at 95° F. Apart from laboratory tests, service results from many thousands of hours running with a wide range of engines (including Burmeister & Wain, Doxford, Fiat, M.A.N., Sulzer and Werkspoor) burning oil ranging from Diesel fuel to oil of 3,500 secs., bunkered at the normal stations, have shown very considerable reductions of rates of wear, relative to the rates obtained with conventional lubricants. Comparison of the service results was effected by lubricating some cylinders with the emulsion lubricant, and some with the oil normally used. Marked improvements were also found in the cleanliness of pistons, cylinders and piston rods.

In any given engine, the quality of the combustion is largely controlled by the condition of the injector, and, to assist in examining this vital part, an instrument has been developed by Engineering Development (England), Ltd. It consists primarily of a thin probe with inset illumination and a viewing lens giving a 4 times magnification by means of which the seating and bores of fuel injectors can be examined.

An article in *The Engineers' Digest* for March, 1956, advocated the use of aluminum-bronze piston rings for small compression-ignition engines. A suitable heat-treatment develops a high natural corrosion and erosion resistance, and the material is readily chromium-plated, if desired. They can be carried directly in the piston ring grooves in aluminum-alloy pistons, but will require to be mounted on an aluminum carrier ring if used with cast-steel pistons. Tests using sulphur-rich fuel, and other fuels producing acid deposits, resulted in rates of wear little in excess of those obtained with higher-grade fuels. The material is also suitable for use as rings in compressors and pumps handling a variety of corrosive gases and liquids.

Two valuable papers on crankcase explosions were read before the Institution of Mechanical Engineers in April 1956; one, "An Investigation into Some Factors Governing the Selection of Protective Devices," by Mr. H. G. Freeston, Mr. J. D. Roberts and Mr. A. Thomas, and the other, "Development of New Protective Devices," by Mr. W. P. Mansfield. The first mentioned paper deals with experimental work carried out in order to investigate the margin of safety provided by particular types of warning device. The direct detection of overheating appeared to offer greatest protection, but there was great difficulty in ensuring adequate surveillance of temperature in all parts of the crankcase. Photo-electric detection gave complete protection from explosions due to oil mists, but only gave an indirect sign of the presence of crankcase spray; but, as the conditions controlling transition from spray to mist are not yet fully known, more work requires to be done in this direction. In particular, more information is needed concerning the temperatures at which mists begin to form.

In the second paper, tests were reported of a crankcase-explosion relief valve, 6 in. in diameter and provided with external wire-gauze flame traps. The tests showed such flame traps to be ineffective when severe explosions were made with mixtures of air and town gas, but it was found that coating the wire gauze with lubricating oil greatly increased the effectiveness of the flame trap. An internal, oil-wetted flame trap of less than half the original size was fully effec-

tive with the most severe explosion that could be produced. An oil-wetted flame trap, covering an aperture in a dividing partition of a cylindrical explosion vessel, fully charged (on both sides of the aperture) with gas-air mixture, was found to limit combustion to the side of the partition on which it was ignited, and the maximum pressure, under such conditions, was reduced to about one-quarter of that reached without the partition flame trap. The outrush of hot gases past an oil-wetted gauze produced an oil mist, which did not ignite even when a Bunsen burner and a blowlamp were used as possible sources of ignition. Internal oil-wetted relief-valve flame traps and partition flame traps were successfully tested on a three-cylinder engine of 9-in. bore, and, from the results, the requirements of a large engine are estimated. The author concludes that the use of the two new devices can provide adequate protection at an acceptable cost.

An interesting group of three papers, presented at the summer meeting of the Society of Automotive Engineers, dealt with cavitation erosion of the water-side of Diesel-engine cylinder liners. This is a fault that has been repeatedly observed during rigorous testing of Diesel engines, more particularly of the high-speed type, and it results in a pitted, honeycomb appearance in which no corrosion products can be detected, although it is often closely related to corrosion effects. The effect is less severe with an inhibited coolant, and the use of harder and more resistant liner material, or the chromium plating of the surface exposed to the coolant, are all found to improve the resistance to erosion. For any particular coolant and liner material, the rate of pitting is primarily affected by the amplitude of vibration of the liner wall. A very satisfactory method of testing the resistance of different materials to cavitation erosion can be carried out with a magneto-striction apparatus, by means of which the test-piece is subjected to high rates of vibration with controllable amplitude. The cavitation effect is so greatly accelerated that factors such as galvanic action and minor variations in the immersing fluid have practically no significant effect on the amount of damage. The rate of loss of weight increases rapidly with increasing amplitude of vibration. It was even demonstrated that damage due to cavitation erosion can be produced on a stationary surface separated by a liquid medium from a vibrating surface. Damage, if present, is usually exhibited with maximum intensity, on the thrust side, and it is considered that certain resonant vibrations are induced in the liner by firing impulses and piston slap.

On one particular series of engines, the amplitude of vibration measured at the point of attack was 0.006-in. Use of a two-piece heavy wall liner, together with the reduction, by 20 per cent, of the cold skirt clearance, reduced the amplitude to less than 0.001-in. Experiment showed that control of piston clearance was the most effective method of reducing cavitation pitting on liners. The engine makers finally developed a cam-ground piston, which provided reduced clearance in the plane of thrust; stroboscopic observation demonstrated that cavitation bubble formation was much more slow with the cam-ground piston than with the standard piston.

Some recent developments in metal coating have been applied to coating aluminum on steel, to provide protection against high-temperature oxidation. One method, employed for protecting internal-combustion engine valves, consists of heating, fluxing and dipping the valve head in commercially-pure molten aluminum, followed by an air-blast to remove all excess molten metal. A valve thus treated is said to have two to three times the life of an untreated valve of the same material.

One of the largest D.C. Diesel-electric installations has been built into the U.S. ice-breaker *Glacier*. The vessel has twin screws, each of which is driven by a D.C. motor continuously rated at 8,450 S.H.P. at 120 r.p.m., with a four-hour overload output of 10,500 S.H.P. at 175 r.p.m. Ten sets of Fairbanks-Morse 12-cylinder, opposed-piston Diesel generators are installed, each having a continuous rating of 1,340 kW. (837 volts, 1,600 amp.) at 720 r.p.m. and the necessary four-hour overload capacity of 1,700 kW., (900 volts, 1,890 amp.) at 810 r.p.m. Complete wheelhouse control of the propulsion motors is provided. Auxiliary electrical requirements are met by four 300-kW. Diesel generators, together with a 200-kW. emergency generator set. The deck machinery, especially designed for use in Arctic conditions, is hydraulically-operated throughout.

The motor vessel *Orpheus*, a tramp ship of advanced design, is to be capable of a service speed of 16 knots. The vessel is powered by a Sulzer, type-7RSD70, seven-cylinder engine, capable of developing 7,000 S.H.P. at 119 r.p.m. The engine is arranged so that, at a later date, it can be converted to use exhaust turbo-charging, which will increase the power and speed to 9,100 S.H.P. and 17 knots, respectively.

GAS TURBINES

As previously reported, the Shell tanker *Auris* is being refitted at Birkenhead, where the gas turbine and Diesel-electric drive are being replaced with a larger gas-turbine installation, coupled to the propeller by mechanical gearing. Meanwhile, the American ship *John Sergeant* has also crossed the Atlantic, powered solely by gas-turbine machinery, at an average speed of 16.81 knots and with a specific fuel consumption of 0.5 lb per S.H.P.-hr. using distillate fuel. A controllable-pitch propeller is used and the reversed torque necessary for maneuvering is provided by this means. The conversion of the *John Sergeant* is quoted as costing over 1 million pounds. The future performance of these two vessels will be awaited with great interest, and they will considerably influence the future trend of main-propulsion gas turbines.

The gas turbine has already established itself in the range of 1,000 kW. as a prime mover for electrical generators, and mention must be made of the Ruston & Hornsby turbine, the remarkable success of

which is a tribute to its designers and builders.

It is accepted that, as yet, the gas turbine cannot equal the thermal efficiency of the Diesel engine, but it can win its place among prime movers by virtue of its natural advantages of lightness, freedom from vibration and reliability when designed with suitable restraint.

The advantage of lightness is of especial importance in naval craft and recent tests (reported at the Gas-turbine Power Conference of the American Society of Mechanical Engineers held in Washington last April) with an internally-fired semi-closed cycle gas turbine, built by the Westinghouse Electric Corporation, for the U. S. Navy, confirmed that such plants are particularly suitable for destroyer propulsion because of (*a*) sensibly constant efficiency over a wide load range, (*b*) low air consumption, (*c*) low space and weight requirements, and (*d*) ease of control.

The efficiency of the regenerative gas-turbine cycle depends on the performance of the heat-exchanger, and, given a satisfactory sealing device, the rotary heat-exchanger combines high thermal ratio with compactness and low cost. At the 1956 Gas-turbine Power Conference, Mr. W. E. Hammond and Mr. T. C. Evans presented a paper in which they described a new form of seal for use with rotary heat-exchangers and suitable for use with plant up to 3,000 H.P.

The United States Federal Maritime Administration is, in effect, providing Government-sponsored research for the United States shipping industry and, besides the *John Sergeant,* three standard war-time ships are being refitted with more modern machinery; one with high-performance steam turbines, another with geared Diesel engines, and the third with free-piston gas generators. This last-mentioned type of machinery has considerable support and popularity in the United States, as well as in other countries, where it is used as a prime mover for the generation of electrical power. In Britain, Smith's Dock Co., Ltd., at their South Bank works, have commenced the manufacture of the S.I.G.M.A., type-GS.34, gasifiers, under licence from Messrs. Alan Muntz & Co., Ltd. The test-bed is particularly well-equipped, and preliminary testing work has been carried out on gasifiers. Design studies of free-piston installations have been made for several types of merchant ship, including a whale-catcher, in which it is proposed to replace a 1,800-S.H.P., four-cylinder, triple expansion steam engine by a 2,000-S.H.P. free-piston installation. For such a power, it is proposed to use two G.S.34 gasifiers, exhausting to a single, six-stage, impulse-type non-reversing gas turbine, to be coupled to a controllable-pitch propeller through double reduction gearing. Two alternative admission points will be provided on the turbine, to enable its consumption to be matched with the gas flow from either one or two gasifiers, so that efficient working will be obtained over a wide power range. With one gasifier generating at an economical load of 60 per cent, the catcher's speed will be 12 knots; full output from one gasifier will give 13¾ knots, and full output from two gasifiers is expected to give a speed of 15¼ knots. In comparison with the original plant, a reduction in fuel consumption of about 40 per cent is expected throughout the foregoing load range, in addition to which the machinery weight shows a reduction of 20 per cent, while there will be made available a considerable space above the main-deck level, which is at present occupied by the machinery casing. Either marine Diesel oil or fuel oil, up to a viscosity of 1,500 secs. Redwood No. 1, at 100° F, can be used.

There are many attractive features about this type of gas-turbine installation. The turbine itself will be working at comparatively orthodox gas temperatures (about 800° F), and it can be comparatively simple and rugged in design, with 100 per cent reliability and accessibility. The free piston gas generators have excellent accessibility, and as they are, mechanically, completely divorced from the shafting, a spare gasifier set can be carried as a safeguard during the early stages of development. Maintenance and spares requirements are more simple than for the corresponding Diesel reciprocator, and furthermore, as the gasifier sets are standardized, a spare set from an early installation, if found to be an unnecessary precaution, could be used as part of a later installation. The benefits of standardization and the ease with which gasifiers could be removed and replaced by shore reconditioned sets, if necessary, are very attractive.

The ultimate success of this type of machinery will depend on the degree of reliability experienced when using residual fuels. In common with the orthodox gas turbine, it cannot, as yet, compete with the Diesel engine on a basis of fuel consumption, and it will have to be seen if it can win a place for itself on account of greater reliability and lower cost of maintenance, including reduced lost earning time incurred by enforced port repairs.

NUCLEAR POWER

The symposium of papers on "Nuclear Energy," read before the Institution of Mechanical Engineers, is a most valuable addition to the published literature on this subject. The paper on "Nuclear Reactors for Power Generation," by Mr. B. L. Goodlet, serves as an introduction to the problems encountered in the design of nuclear reactors for power generation. Part I. specifies problems of reactor technology under the headings of reactor physics, reactor materials, radiation and radio-activity, and engineering design. Part II. illustrates the development of various reactor types by the application of reactor theory and technology. Part III. deals with the operation of nuclear-power plant. An appendix summarizes reactor physics in terms familiar to engineers.

"Shielding against Nuclear Radiation" was dealt with in a paper by Mr. C. E. Iliffe. The physical sources and interaction of the various radiations, which have to be dealt with in nuclear reactors, are explained and manners of shielding are described. The paper concludes with a discussion of heat generation in shields and of likely future developments.

Professor J. Diamond and Mr. W. B. Hall presented

a paper on "Heat Removal from Nuclear Power Reactors." The influence is discussed, of the physical characteristics of the coolant and of the extended surfaces of the fuel elements on the maximum coolant temperatures and on pumping-power losses for a given rate of heat removal, and gaseous and liquid coolants are compared. Simple methods are suggested for an initial analysis of the heat-transfer aspect of a reactor cooling problem; an appendix gives an illustration using an example of gas cooling.

The subject of "Steam Cycles and Nuclear-Power Plant" was dealt with by Mr. R. E. Zoller, B.Sc. (Eng.). In his paper, he discusses the use of water, gases and liquid metals, as coolants, and corresponding suitable single and multi-pressure steam cycles for various reactor systems. Where the power consumption of the coolant circulating system is appreciable, the selection of the optimum operating condition is illustrated. Methods of avoiding excessive moisture in the turbine exhaust are suggested. For reactor power plants limited to low coolant temperatures, the use of separately-fired superheaters is recommended as being worthy of consideration, on account of the high utilization efficiency of the fuel oil and the low overall capital cost of the resulting additional power output.

A "Survey of Atomic Power for Marine Propulsion" is published in the Bulletin of the American Society of Naval Architects and Marine Engineers, the author being Mr. D. F. Tackett. A comprehensive summary is given of the principles of reactor theory and technology, followed by a discussion of reactor kinetics, control, and materials, including fuels, moderators, reflectors, coolants, control rods, cladding and shielding materials. The author discusses two particular reactor systems, in order to point out some of the features that may be included in a marine power plant. The first system is a gas-cooled heterogeneous reactor with the coolant directly driving a gas turbine of the closed-cycle type. Control is accomplished comparatively easily, by varying the coolant gas pressure, but because the coolant is a gas, rates of heat transfer are comparatively limited, and the reactor cannot be very "fast"; consequently, the limiting minimum size is comparatively big, with correspondingly heavy weight of shielding material. The most suitable coolant is helium, and carbon dioxide is a possibility. The second system discussed is a homogenous liquid-fuel reactor, in which the liquid fuel circulates through the reactor and carries the heat out with it. The liquid fuel can either transfer its heat directly to the steam generator, or it can do so *via* an intermediate liquid-metal circuit. In either case, because of the possible high rates of heat transfer, an enriched fuel can be used, with consequent diminution of the reactor size and weight of shielding material.

In an article in *Marine Engineering* (January and February, 1956) entitled "Nuclear Power for Merchant Ships," the authors—Mr. C. H. Johnson and Mr. P. V. Johnson—state that they consider the enriched fuel required for use in medium and fast reactors is too expensive for use in merchant ships, and they proceed to consider the heterogeneous reactor as the most likely to be economically attractive. They describe, in some detail, heterogenous reactors using pressurized-water cooling, liquid-cooling, the dual-cycle boiling water and closed-cycle boiling water. The closed-cycle boiling water reactor is considered to be, at present, the most attractive marine proposition, where saturated steam from the reactor condenses in a shell and tube heat-exchanger, and generates steam for use in the turbines. The principal advantages of this system over the boiling-water dual-cycle reactor are *(a)* a possible reduction in the amount of secondary shielding, *(b)* access to the turbines and other secondary-circuit equipment not restricted by radio-activity, and *(c)* the secondary steam can be superheated in a separately-fitted superheater. The advantages over the pressurized-water reactor plant are claimed as *(a)* absence of pumps or valves in the primary loop, *(b)* lower pressure in the primary loop for a given secondary steam temperature, *(c)* constant secondary steam pressure over the load range, and *(d)* substantial reduction in cost of generated steam.

To obtain high efficiencies from gas or steam turbines, the temperature within the reactor will have to be of the order of 1,400° F, unless some external source of topping-up heat is to be used. The crux of reactor design is the development of fuel elements to operate at such temperatures, and to be stable against thermal stress and against severe radiation damage. The main burden of development still falls on the metallurgist and on prolonged testing of experimental fuel elements in the materials-testing reactors now available at various centers.

It appears to be the general opinion that, for marine propulsion, the *ultimately* preferred cycle will be the gas-cooled reactor, coupled to a closed-cycle gas turbine, whereas, *at present,* the only suitable cycle would be based on one of the water-cooled reactors coupled to a steam turbine.

The obvious choice for the first nuclear-powered merchant ship is a tanker of 40,000 tons or more, primarily because of the high utilization which is possible—a tanker spends 80 per cent of its life at sea, and even when in port, the steam demand for pumping may be as high as 40 per cent full power. There is a difference of opinion as to how soon it will be possible for a tanker so equipped to compete with conventionally powered vessels. The United States Maritime Commission forecasts that it will be possible within five or six years, and they recommended that the construction of experimental vessels should be started as soon as possible, so that the experience gained could be applied to the large building program which is anticipated in the early 1960's. Other forecasts are not so optimistic and see the fabrication and cladding material costs preventing the successful commercial competition of marine nuclear power

plants for a considerably longer period than five or six years.

It is learned that the United States Government has decided to go ahead immediately with the construction of a merchant ship to be powered by a pressurized-water reactor and driven by steam turbines.

An experimental reactor, organic moderated reactor experiment (O.M.R.E.), of about 16,000-kW. heat output, is being built for the U.S. Atomic Energy Commission, in which an organic compound, diphenyl, serves both as moderator and coolant. The high hydrogen content of diphenyl makes it an excellent moderator, and its relatively high boiling point allows serviceable temperatures to be used in the heat-transfer system, without the use of high pressures. Further advantages are expected because *(a)* it only becomes slightly reactive on exposure to nuclear radiation, *(b)* it does not react readily with uranium, and *(c)* it has practically no corrosive effect on standard materials of construction.

Yet another means of water moderating and cooling a reactor is discussed by Mr. C. F. Leyse in *Nucleonics* of July, 1956. In the ordinary boiling-water moderated reactor, the core is completely submerged in water and the usual method of control is by means of absorption rods. But it has been demonstrated that reactivity can be controlled by varying the water-level and only partially immersing the core, so that variation in the feed-water rate can be used to control the reactor, and control rods are not needed. Such a reactor is named an automatic boiling column reactor (A.B.C. reactor). The potential advantages of such a reactor, compared with the ordinary boiling-water type, are summarized as greater simplicity of control, better load response, high fuel burn-up, and less sensitivity to loss of reactivity, due to poisoning by the release of xenon gas.

The problem of containment of radio-active material in the event of damage, particularly when in port or congested waters, is of fundamental importance in marine nuclear application. A paper on "Some Safety Considerations of Nuclear-Power Reactors" was presented by Mr. C. D. Boadle to the Joint Nuclear Marine Propulsion Panel in November last, and deals with methods of control of some of the operational hazards. The absoluteness of the requirement that in no circumstance whatever shall radio-active material be discharged from a reactor, imposes an unusually severe demand on the designer, which is naturally reflected in the conservatism of early designs. Safety precautions are not only concerned with preventing the release of radio-active material, but are also concerned with preventing mishaps to the reactor core or other radio-active parts, which cannot be made good by the normal shielded machinery used for changing core components. In a ship, such a mishap would result in loosing motive power. Nuclear reactors exhibit many characteristics which are quite unlike those of other power producers, and the author indicates them. Some provide valuable self-regulating features, while others provide the means of rapid power surges, capable of causing serious damage unless controlled by a monitoring and control system. For many types of reactor, the final guarantee against discharge of radio-active material, following an accident, must be provided by complete containment in a gastight shell. In collision or stranding, there is even danger of rupture of such a shell, so that great interest centers on possible future systems employing continuously processed liquid fuels. Such a system will offer a substantial reward in terms of safety, as it will provide a method of dispensing with the need for the large amounts of inbuilt reactivity, which are in practically all present-day reactors, and which form the greatest hazard.

GEARING

In the highly competitive field of bulk-carrying, the demand for large powers on single shafts has led to the design and manufacture of large and more heavily-loaded double-reduction gearing for use in connection with steam turbines. In the past 15 years, considerable advances have been made in gear-cutting accuracy. Nevertheless, troubles and failures of various kinds continue to occur, and Mr. S. Archer, in his paper entitled "Some Teething Troubles in Post-war Reduction Gears" (read before the Institute of Marine Engineers in September, 1956), deals with this matter. The paper draws attention to a number of typical gearing troubles, which have been experienced over the past 10 years, and, where possible, suggests probable causes and precautions for their avoidance. Statistics of gearing troubles investigated during a recent two-year period are tabulated and analyzed.

At the same meeting, Mr. W. H. Darlington presented his paper on "Some Considerations of Wear in Marine Gearing," in which he dealt with the design, manufacture and operation of three sets of double-reduction gears, installed in the vessels, *Nestor, Neleus* and *Theseus*. All three sets were shaved throughout, and one was fitted with hardened and ground pinions with a soft main wheel. This latter set suffered no wear, but the other two sets had a transient wear problem, which cured itself on continued running. The wear was unusual in that it occured between the second-reduction pinions and main wheel (while the first-reduction elements were unaffected, although material and method of lubrication were common to both), and it was confined to the dedenda of both mating teeth with no sign on either adenda. Detritus from the wear process, collected in the magnetic filter, was in the form of dust and flakes, rather than pyramidal pieces due to pitting, or lumps due to scuffing. No complete explanation of all the unusual features is arrived at, but the author makes a strong plea for a proper "running in" treatment, particularly for highly-loaded gears which are not hardened or ground.

The Thomas Lowe Gray Lecture before the Institution of Mechanical Engineers, last year, was presented by Mr. A. W. Davis on the subject of "Marine

Reduction Gearing." Attention is first drawn to the essential requirements of gear design, and to practical features of machining and finishing of gear teeth. Requirements for the production and maintenance of good alignment are discussed and followed by considerations arising from pinion distortion. It is suggested that small face-width ratios, coupled with high loading, induce unnecessary sensitivity to bearing misalignment. Work carried out by the Parsons and Marine Engineering Turbine Research and Development Association (Pametrada) has led to the development of a smaller length-to-diameter ratio on high-speed bearings, which is welcomed, but the tendency to reduce diametral clearance is not favored. The selection of materials is still open to choice, and it is considered that the mating characterisics of alloy-steel gear elements require considerable further study. Case-hardening, followed by grinding, has proved very successful for small gears, but a similar development in marine gearing is greatly handicapped by the difficulty of case-hardening a large rim, without such growth and distortion as to render subsequent profile grinding a lengthy and costly operation. Nitriding or induction hardening may prove to be more economical for these big gears.

A new dual-purpose machine for hobbing and shaving large turbine gears has been developed by the machine tool division of the David Brown Industries, Ltd. Four sizes are being manufactured, capable of producing gears of from 60 to 175 in. in diameter, and pinions and first-reduction wheels, of from 6 to 60 in. in diameter.

AUXILIARY MACHINERY

There has been developed by the Siemens-Schuckert Company a 3-ton A.C. cargo winch, in which the simplicity and robustness of the simple A.C. squirrel-cage motor is largely retained, and hoisting and lowering characteristics, comparable with those of a standard 3-ton D.C. winch, are achieved. The Siemens winch has two squirrel-cage motors on a common shaft, together with three stator windings, which have four, eight and 32 poles, respectively. The same firm has also developed A.C. anchor and warping capstans, and an A.C. "constant-voltage" generator. This latter machine has an excitation current made up of two superimposed components, one dependent on the load and the other independent. The effect of this arrangement is to reduce the generator voltage fluctuations that tend to occur when squirrel-cage motors are switched directly on line.

It is now over 3½ years since two single-speed squirrel-cage A.C. winches were fitted in the Brocklebank vessel *Maskeliya*. The main switch is a triple-pole contactor, and the motor can be immediately reversed without delay or damage. There have been no reports of damage to cargo by snatching, which may be due to the D.C. automatic, magnetically-released disc brake which is fitted. The design duty is 3 tons at 130 ft. per min. in low gear and 1½ tons at 260 ft. per min. in high gear.

An analysis has been published of the performance of the three-phase A.C. electrical-supply system of the *Cap Blanco* during a round voyage between Europe and South America. On the outward passage, the cargo was of a general character, while on return, a bulk cargo and a considerable quantity of refrigerated cargo were carried; so that the performance at sea was tested, both with and without the refrigerated load, as well as the operation of the winches with various types of cargo. The current, voltage and power output of the generators were continuously recorded. The most severe demands were made when handling the bulk cargo, and it was noted that, with a basic load of 100 k.W., the rated output of one generator (240 kW.) was only reached, or exceeded, when all 14 winches were simultaneously in operation. The rated output of two generators (480 kW.) was never exceeded. The observed voltage fluctuations were stated not to exceed the values found for winch operation with D.C. systems. At low-rope speeds, the A.C. winch requires only a small current, whereas the D.C. winch, with series and parallel resistances, draws full power from the generator at the first step. The required generator output, therefore, is no higher than for a D.C. system.

MAINTENANCE AND REPAIR

"Some Aspects of the Application of Planned Maintenance to Marine Engineering" was the subject of a paper presented to the Institute of Marine Engineers, in December, 1956, by Mr. W. H. Falconer. For ships' machinery, as in all other applications of planned maintenance, the fundamental requirement is the elimination, so far as humanly possible, of the risks of a breakdown during service, and the aim is the improvement of reliability and an overall reduction of costs. The attainment of such aims can well repay, considerably, the trouble and expense of the necessary record keeping. In the words of the author's own summary:—

"The approach to the resolution of engineering problems is continually undergoing changes. Modern marine machinery requires not so much the 'improvisation' approach as that of 'renewal,' in order to engender that high degree of reliability which planned maintenance sets out to provide. Guaranteed availability cannot be obtained simply by providing much more highly-rated machinery than normal service requires. A simple example of planned maintenance is in recording the rates of liner wear in Diesel engines. If carried out systematically (and, preferably, by the same person), the impact of extensive renewals at one overhaul is avoided, together with the engineering hazards of running on excessively worn liners."

It is pointed out that effective planning must be based on a knowledge of the time required to execute repairs and preventive maintenance. At present, cargo-handling schedules for carriers of dry goods do not impose any great strains on port repair facilities; but when trade conditions allow a quicker turnround, schedules may have to be revised. The author

illustrates the argument with many interesting examples, and mentions some of the equipment and aids that have been found most useful.

CORROSION

A comprehensive paper, entitled "Corrosion of Cargo Ships and its Prevention," was presented by Mr. H. J. Adams and Mr. J. C. Hudson to a joint meeting of the Institution of Naval Architects and the Institute of Marine Engineers. The paper excludes the subject of corrosion of oil tanks, but covers most other aspects. The general introduction discusses the occurrence of corrosion in ships, the effect of steel quality, the effect of design and the effects of welding. The large section on the corrosion of under-water plates deals with typical cases and details protective measures for maintenance painting.

Laboratory tests have shown that zinc anodes are very sensitive to impurities, which promote the formation of a tenacious surface oxide film, and also to the iron content, which should not exceed 0.0014 per cent. Traces of cadmium and lead also have an adverse effect, but aluminum seems to be beneficial. The usual means of attachment by bolts often proves to be unsatisfactory, due to local wastage in way of the exposed ends, leading to slackness and poor electrical contact. The U.S. Navy now uses a hull slab (12 in. by 6 in. by 1¾ in.), which has two cast-in steel straps. These straps may be fastened to the hull either by tack-welding or by bolts. A high current output is reported to be maintained for two years. On no account, of course, must the anodes be painted.

The cathodic protection of steel cargo tanks in contact with sea-water is developed in two phases. The first requires the comparatively high current densities necessary to polarize the steel quickly, and to develop the alkaline calcareous deposit for immediate protection under non-ballast conditions; the second requires a lower current density in order to maintain the protection initially provided. The long-term second phase of protection is usually energized by sacrificial anodes of suitable material, whereas there are two widely used means of providing the initial boost for the inception of protection. In general, it now appears that United Kingdom shipowners prefer the use of an external source of direct current (later disconnected) for the initial boost, while United States owners use a greater number of main anodes for initiation.

The cost of protecting all the tanks of a 20,000-ton tanker engaged in the white-oil trade, using standard magnesium anodes for initial boost and main protection, has been stated to be 14,000 pounds; this figure includes materials, design and supervision, but not labor. If the tanks can be filled with sea-water during a convenient docking period, so that an initial boosting current can be used to build-up calcareous deposits, then the overall cost can be reduced by 10 to 15 per cent. An economical type of anode has been developed having fins, so that it combines the function of main and booster anode in one. The fins provide the initial high current and after they have been sacrificed, the remaining surface provides the equilibrium current.

Nos. 2 and 3 tanks in the coasting tanker *Shell Welder* have been protected in this two-stage manner and six-monthly inspections, up to date, have shown a great reduction in metal wastage. The anodes presented an even and typical corrosion pattern. The periods during which ballast was carried has varied from a few hours to a week; the principal cargoes have been gas oil and motor spirit.

There is at least one proprietary coating now available for application to the interiors of cargo-oil tanks, which is capable of withstanding the action of oil cargoes and the hot sea-water used for tank cleaning. Furthermore, it is claimed that it does not collect a static electrical charge. Practical tests of one such product were carried out on tank surfaces in the R.F.A. *Wave Protector*, which were exposed as follows:—High octane aviation spirit, 92 days; kerosene, 33 days; Diesel oil, 17 days; clean salt-water ballast, 27 days; dirty salt-water, 11 days; and some of the tanks were filled with sludge oil for five days. During this test period (185 days), the ship was degassed by the Butterworth system eight times. The result has been so satisfactory that the Admiralty are making extended use of the coating in other R.F.A. vessels. Certain Shell tankers have also had encouraging results over a year's test period. The labor and material costs of application are estimated to be less than half that of cathodic protection. Other coatings are available when edible oils are to be carried and protection can also be obtained against alkali cargoes.

A latex cement has been developed, which consists of a mixture of high alumina cement with concentrated natural rubber latex. It provides a coating, with a high bond strength, to practically all surfaces, even wet, and a high tensile strength coupled with considerable resilience, resistance to thermal shock and resistance to physical attrition. It can resist attack by weak acids and alkali and is impermeable to water. It makes a useful coating for iron and steel, on to which it is best sprayed, and it is capable of bridging over isolated spots of rust or mill scale, filling in pits and providing a surface well-suited to support a synthetic-resin coating, forming a combination highly resistant to corrosive influence. The simple latex-cement coating can be advantageously used in conjunction with cathodic protection, as it assists in distributing the current over a larger area and remains unaffected by the cathodic evolution of hydrogen.

Nylon has been tried as an anti-corrosive protection. It is fed to a spraying gun as a powder and is melted on its way out in an oxy-acetylene flame. On striking a pre-heated (previously cleaned) metal surface, it forms a homogeneous film and requires no further treatment.

An anti-corrosive treatment, which has proved successful for deep tanks, consists of an initial shot-blasting, followed by metalizing with a flame spray gun,

using zinc or aluminum, to be followed, in turn, by a coating of plastic sealer to fill any pores in deposited metal. Experience with certain vessels carrying lubricating oil in bulk, indicates that four years' life can be expected before touching-up is necessary. A similar method, using aluminum for the metal coating, is expected to prove suitable for tanks carrying edible oils.

An interesting new product, non-toxic and non-caustic, which has a strongly solvent action, has been developed. This product will be of great assistance in tank-cleaning, due to its action in breaking-down oily residues. It is most effective when sprayed directly on to the surfaces just prior to hot-water washing, or it can be mixed with the washing water by gravity-feeding into the cleaning pump suction. Its use reduces the number of washes and the maximum temperature, and it is particularly useful for the thorough cleaning when changing from the carriage of crude oil to distillate fuel.

MATERIALS

The symposium of papers on "The Fatigue of Metals," arranged jointly by the British Institution of Mechanical Engineers and the American Society of Mechanical Engineers, forms a comprehensive collection of up-to-date information, which defies condensing for an article such as this. A smaller symposium, but on the same subject, has also been arranged in Holland.

Outside these symposia, there have been several publications on the subject of fatigue, and one of considerable interest is by Mr. C. L. Bore, entitled "Presentation of Fatigue Data for Fatigue Life Calculations," published in the Journal of the Royal Aeronautical Society (May, 1956). Fatigue data are charted in a manner which clearly shows the effects of mean stress, residual stress and pre-tension, and is well-suited to the calculation of stress-concentration effects, including that of plastic relief. The use of such a charting method provides a means of readily comparing relative fatigue strengths and structural efficiencies of different materials; it clearly demonstrates that, in certain circumstances, a high tensile-strength material may have a considerably lower fatigue strength than a medium tensile-strength material for a given endurance period, and a correspondingly lower endurance for a given stress level. Practical examples of the use of the chart are given.

Advancing steam conditions lead to the employment of alloy steels for steam pipes, which, in turn, have created problems of welding and construction. In a paper on "Welding of Steam and Feed Pipework for Marine Installations," read before the Institute of Marine Engineers by Mr. J. Chamberlain and Mr. W. L. Roe, the authors discuss the welding, heat-treatment and non-destructive testing of joints in alloy steels made by manual methods only. Recommendations are made regarding the suitability of certain steels for specific temperature ranges. The paper refers to *(a)* types of welded joints and preparation of tubes for welding, *(b)* welding process and procedure, *(c)* filler rods and electrodes, *(d)* preheating, *(e)* post-welding heat-treatment, *(f)* non-destructive examination, *(g)* repairs to faulty welds, and *(h)* training, testing and supervision of welders.

On the same subject of butt-welding pipes, Mr. R. P. Newman presented a paper to the Institute of Marine Engineers on "The Influence of Weld Faults on Fatigue Strength, with reference to Butt Joints in Pipe-lines." It is shown that, for the conditions applied, the root zone of welds, with and without backing rings, exercise a predominant influence on fatigue behavior. Except for the case of lack of penetration, other defects had no significant effect on fatigue strength, because of this overriding influence of the root zone, and hence no correlation between general radiographic appearance and fatigue behavior was found. The need to maintain a reasonably general standard of welding such joints is not necessarily disproved; what is indicated is that, if the welding procedure in all its aspects is well-planned and executed, particularly in regard to the root run, then the full application of radiographic examination is probably unnecessary.

The stress-relieving by induction heat-treatment of heavy-duty welds has been made more easy by the development (by Messrs. Brown, Boveri & Co., Ltd.) of a special heat-resistant induction cable, the insulation of which can withstand 700 volts up to a temperature of 1,380° F without need for water-cooling, and up to 1,740° F if arrangements are made for water-cooling the inductors. The cable, which is flexible, can be laid on or wound round the component to be treated, and the absence of inductor cooling water, over the usual temperature range, eliminates the possibility of accidental chilling of the workpiece. Such a cable inductor can be used for heat-treating welded seams in turbine rotors, pipes, boilers and castings, and is particularly suitable for the preliminary heating in connection with the shrinking of large gears or flywheels on to shafts. In this latter case, the symmetrical heat distribution eliminates asymmetric deformation, so that subsequent dynamic balancing is greatly simplified.

An article discussing the principle of induction heating, and surveying its use for surface hardening, by Mr. G. W. Seulen, appeared in *Metal Treatment* (August, 1956) under the title of "Induction Hardening as a Means of Increasing the Resistance to Wear of I.C. Engines and Machinery."

In an article on "Brittle Fracture" by Mr. G. Vedeler, in *Bulletin Technique du "Veritas"* (September, 1955), it was pointed out that the brittle fracture in large welded ships, especially supertankers, can be traced to the comparatively coarse-grain structure of the thicker plate sizes, and that steel of a finer grain size must be used to avoid risk of fracture. The grain structure of thick plates can be improved by the addition of small quantities of silicon or aluminum, and by delaying the final rolling until the temperature has fallen appreciably below

that which normally prevails. Det norske Veritas suggest that, for such thick plate steels, a Charpy Vee-notch test and a maximum grain size should be prescribed. All steel rolling mills are prepared to fulfil the first condition without greatly increasing the cost, but the author reports that British prices for fine-grained, thick, steel plating are excessive in comparison with those of other steel producers.

Polyvinyl chloride is hardly attacked by either calcium or sodium chlorides, and it has a longer life than most stainless steels in brine solutions. Thus, typical applications are brine piping and cooling water-lines in air-conditioning plant, and exhaust ducts for the removal of corrosive fumes or fluids at moderate temperatures and pressures. The chief limitations to this piping are temperature and strength. Further details concerning the use of this material is contained in an article by Mr. W. Chapman in *Air-conditioning, Heating and Ventilation* (July, 1956), and entitled "Characteristics of Polyvinyl Chloride Pipe."

Plywood coated with a plastic, compounded from a polyester resin and glass fiber, has been found to be very successful in the banana-carriers *Bremerhaven* and *Nordenhaven*. Tests on such material show that the mechanical and chemical properties are superior to those of normal wooden linings. The coating is practically unaffected by banana or orange juice, fish, meat or the usual cleaning solutions. It absorbs little moisture and retains no odor from cargo. For cleaning, it only requires to be washed down with a normal cleaning solution, followed by a water rinse. Such a treatment keeps the surface smooth and clean indefinitely.

MISCELLANEOUS

Fire Detection and Prevention.—

A most useful symposium of papers on "Fires in Ships" was presented to a joint meeting of the Institute of Marine Engineers and the Institution of Naval Architects in October, 1956. The separate papers are: —"Survey of the Causes and Methods of Extinction of Fires in Ships," by Mr. F. J. Welch; "Principles of Fire Organization in Ships at Sea and in Port," by Lieut.-Colonel A. G. Bates; "Naval Procedure in Relation to Fire Organization," by Mr. L. T. Carter, R.C.N.C., and Captain H. C. Hogger, R.N.; and "Research in Relation to Ship Fires," by Mr. S. H. Clarke and Mr. S. A. Hodges.

The position regarding fires in ships in port is indicated by the fact that, after the fire in the *Empress of Canada* in 1953, very little could be found to be added to the recommendations of the 1950 Working Party Report on Fire Prevention and Fire-fighting in Ships in Port (issued by the Ministry of Transport), except that they should be followed instead of being ignored. Further improvements at sea appear to lie in: —Extension of fire-mindedness and training in fire-fighting; provision of automatic fire-detection in holds, including audible alarms; improvements in methods of sealing openings efficiently and quickly, particularly in machinery spaces; maintenance of pressure on the fire-main for instant availability; increased attention to cleanliness and prevention of oil leakage in machinery spaces; insulation of all hot surfaces to prevent ignition of accidental leakage; placing oil tanks of all descriptions where they cannot become involved in flame from a major fire sweeping up the inside of machinery casings; and making machinery casings fire-resistant. A very extensive bibliography is given.

In connection with the problem of maintaining ship stability, Mr. E. T. Hayward (in the Quart. I. Fire-E., Edinburgh, Vol. 76) describes an ejector pump designed specifically for use in fire-fighting duties. It is made of light alloy, weighs only 9 lb. and is intended to be immersed in the loose water from fire hoses. When energized with a ¾-in. nozzle on test, an ejector discharged 300 gallons per min. through a discharge height of 8 ft.

A ship's fire-mains should have 100 per cent availability, but certain fouling growths have, on occasion, reduced flow rates by 90 per cent in ferrous mains. Fouling in copper-nickel pipes is not so severe, but it can still be considerable. Temperatures in excess of 60° F favor the rate of growth of fouling, which is thus often severe in piping close to engine-rooms and boiler-rooms. Regular chemical cleaning would appear to be necessary, to provide the high degree of availability required.

Lubrication.—

Teflon has a remarkable combination of chemical and physical properties. It is non-adhesive, has the lowest co-efficient of friction known for solids, and is chemically inert with almost all substances. It can be widely used for dry lubrication. In a test for resistance to abrasion, a steel rod coated with 2 mm. of Teflon withstood 70,000 strokes of a reciprocating ground-glass surface; a conventional abrasion-resistant finish under similar loading was destroyed after a few hundred strokes.

There are many specialized cases where dry-rubbing bearings are inadequate, and where it is impracticable to use liquids or greases, and where gas can be successfully used as a lubricant. The two basic classes of gas-lubricated bearings of both journal and thrust type are the hydrostatic, and the self-acting or hydrodynamic. In the hydrostatic gas bearing, the load is sustained by the hydrostatic gas pressure in the clearance space; there is always finite leakage of gas, and pumping power required increases roughly as the cube of the clearance. The self-acting type of bearing generates its own hydrostatic pressure within the clearance space by virtue of the viscosity of the fluid in which it is immersed and the relative motion of the bearing elements. A paper on "Principles and Applications of Hydrodynamic-type Gas Bearings" was read before the Institution of Mechanical Engineers in October, 1956, by Mr. G. W. K. Ford, Mr. D. M. Harris and Mr. D. Pantall. Two specific developments are described; one, a pump for

circulating carbon-dioxide gas at 100 lb. per sq. in. and 150° C through a loop in a nuclear reactor; the other a gas-bearing motor driving a pump for molten radio-active bismuth, the whole within a hermetically sealed container. Experimental results and techniques are reported.

Work carried out on stepped thrust-bearing investigations was reported by Mr. R. C. R. Johnston and Mr. C. F. Kettleborough, to the Institution of Mechanical Engineers in February, 1956. The running oil-thickness and friction characteristics were determined for a range of speeds, loads and inlet temperatures for several different angular positions of the radial step, and also for two curved steps.

Instruments.—

A magnetic filter capable of removing ferrous particles so small as 0.00004in. from liquids has been developed by Philips Electrical, Ltd. The powerful permanent magnets used are surrounded by a thin non-magnetic casing, while the liquid to be filtered passes over the outside of the cage and is not brought in physical contact with the actual magnets. The ferrous particles are magnetically pulled on to the cage surface; and when the elements are taken out for cleaning, the magnets are removed from inside the cages, which, being themselves non-magnetic, are easily cleaned. The filters are built in capacities ranging from 12,000 to 40,000 gallons per hour.

For continuous satisfactory operation, most electrical and electronic-control equipment used in ships requires to be mounted on effective shock and vibration absorbers, which should have good damping characteristics for both transient and continuous vibration or shock. They should also be capable of operation at high ambient temperatures in the presence of oil, petrol and acids, either liquid or vapor. An all-metal shock-absorber and vibration damper has recently been developed in America, aimed at meeting these requirements, in which the core of a stainless-steel spring is packed with cushioning material woven of stainless-steel wire. Two ring-shaped pads of the same material are fitted and limit the movement of the instrument-foot resting on the cushioned spring, so that the load-displacement characteristic of the whole suspension rises steeply at the higher loads. At resonance, such an arrangement is claimed to have five to seven times the damping effect of rubber, and it is also claimed that it can satisfactorily handle transient loads resulting from accelerations up to 30 g. The temperature range is given as—130° F to 347° F.

A prototype of a viscosity meter, called the Viscotherm, has been installed in the fuel-line of one of the engines of the *Willem Ruys* and has been in service for over 3,500 hours with very satisfactory results. A small amount of fuel is continuously extracted from the fuel-line and pumped through a capillary tube, and the pressure drop across the capillary is used as a measure of the viscosity. The pressure drop is shown on a special differential gauge. This viscometer is of Dutch origin. Another such instrument, of German development, is based on measuring the time taken to fill a particular float chamber filled through a capillary tube with a given pressure drop. The time is measured automatically, and corresponding viscosity can be read from curves.

A further range of thermo-junction discs, suitable for measuring heat-flow rates, have been developed by Messrs. Joyce, Loebl & Co., Ltd. The earlier discs gave an output of 2.5 microvolts per BTU per sq. ft. per hour. This is increased to 714 and 250 microvolts for the latest designed discs 4.3in. and 2.0in. in dia., respectively. As they are constructed of a polythene matrix, in which thermo junctions are embedded (about 300 per sq. in.), the maximum temperature at which they can operate is 160° F.

Anchors.—

The Spek anchor has been widely adopted by Dutch shipowners and is now being manufactured in Germany. It is a form of stockless anchor, so designed that the center of gravity of the head lies on the pivoting axis. As a result, the head comes to equilibrium at any angle and it will easily adjust itself to the angle of the ship's side when the points of the flukes make contact with the side plating.

EDUCATION.

The University training of marine engineers has been considerably strengthened at King's College in the University of Durham, Newcastle-on-Tyne, by the endowment of a Chair of Marine Engineering. This was made possible largely by the generosity of the engine-builders and shipbuilders of the North-East Coast, and the first Professor, Commander C. H. Chambers, R.N. (Rtd.), has recently been appointed. There is thus a great opportunity for shipowners to take advantage of the facilities now available by sponsoring the best of their engineering cadets and helping them to take the course at the University. The intake to the first year of the Cadet Scheme has now reached Ordinary National Certificate standard, and a good pass at this level will merit consideration for matriculation exemption and entrance to the University. If British ships are to use, successfully, the results of modern research and development, an increasing intake of University-trained engineers is required by the shipowners and engine-builders, and the further training of selected engineer cadets, as indicated in the foregoing, would appear to be one way of ensuring the necessary intake.

JAMES J. TURNER

SELECTION OF DIESEL PROPULSION PLANTS FOR NAVAL VESSELS

THE AUTHOR

is a graduate of the U. S. Merchant Marine Academy in the Class of December 1948. He served on board Merchant Vessels as a cadet and on board Naval Vessels as an Engineering Officer and is presently employed in the Bureau of Ships "Performance and Scientific Section" of the Machinery Design Branch.

INTRODUCTION

DIESEL ENGINES used on Naval Vessels are usually off the shelf items whose characteristics are known. This fact relieves the ship designer of the responsibility of specifying the main propulsion plant characteristics. However, this apparent blessing is a dangerous engineering pit fall because the total horsepower required for a given ship can be arrived at in many different ways with many different type engines.

In order that the propulsion plant selected for a given ship is optimum the following procedure has been developed.

DISCUSSION

The primary basis for selection of one type diesel propulsion plant over another for Navy application is: "Which plant has the least total weight of machinery plus fuel for a given cruising range." To determine the required quantity of fuel to meet endurance requirements, the following data must be obtained or estimated—

- Full power shaft horsepower (f.p. s.hp.)
- Full power speed.
- Full power propeller revolutions per minute (rpm).
- Cruising speed and endurance.
- Cruising propeller rpm. Assume straight line function with speed on displacement type hulls if no other data are available.
- Total brake horsepower (b.hp.) required. Transmission efficiency assumed according to type drive being considered.
- Speed power curve for the ship. For most ships the power to drive a vessel varies approximately as the cube of the ship speed or propeller rpm.
- Ship speed in knots = full power speed in knots $\times \sqrt[3]{\text{per cent f.p. s.hp.}}$

By using multi-engine installations, some choice of operating conditions imposed on the engines is possible. For any type of internal combustion engine, the output power may be expressed as:

b.hp. = rpm × brake mean effective pressure (b.m.e.p.) × constant. This is quite similar to the equation,

b.hp. = rpm × torque × constant.

If all values are expressed as a percentage of rated, the above equations become:

per cent b.hp. = per cent rpm × per cent b.m.e.p. or
per cent b.hp. = per cent rpm × per cent torque.

One characteristic of an internal combustion engine is that rated torque or b.m.e.p. cannot be exceeded without harmful effects unless overload provisions have been made.

Further examination of the preceding equations indates that it is possible to obtain infinite combinations of per cent b.m.e.p. and per cent rpm with less than 100 per cent b.hp. When there is a fixed reduction ratio between engines and propeller, and all engines are in operation and assuming a rpm cubed —b.hp. relationship the per cent b.m.e.p. will vary as per cent rpm squared.

If the resulting per cent b.m.e.p. is too low for good engine operating conditions, it may be increased by decreasing the number of engines in operation. The resulting per cent b.m.e.p. would be:

per cent b.m.e.p. = $(\text{per cent rpm})^2 \times$ number of installed engines divided by number of operating engines.

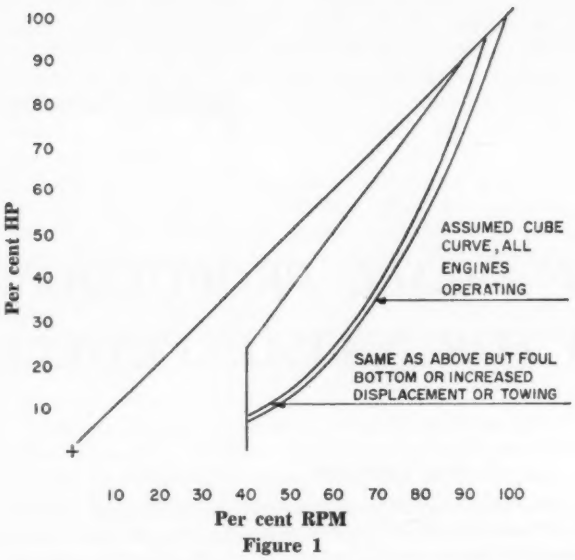


Figure 1

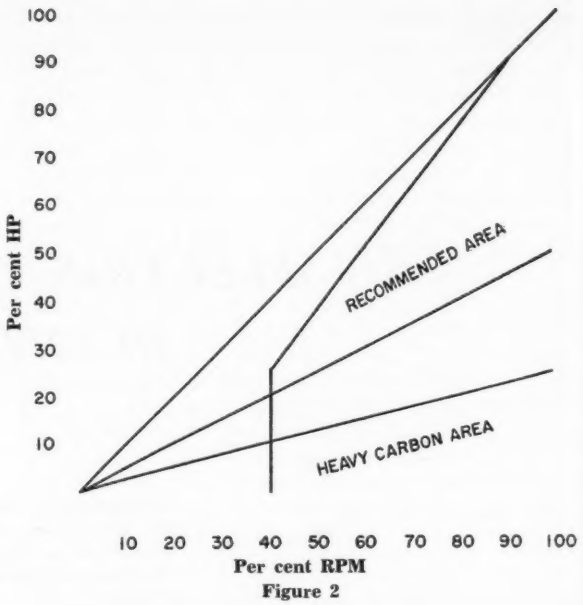


Figure 2

The above assumes constant transmission efficiency but is usually quite satisfactory for a preliminary analysis.

For a more detailed analysis, the actual tranmission efficiency at the various operating conditions should be considered. This type of analysis may be used for any number of engines and any type of installation.

Where a fixed reduction ratio between engines and propeller is not used, such as on d.c. electric drive, care must be exercised in determining the engine rpm.

Where a controllable and reversible pitch propeller is used, the cube relationship between s.hp. and rpm will not apply except for constant pitch operation.

When establishing the s.hp. versus rpm curve and when determining the engine rating required, the various conditions of the operating ship must also be considered. These conditions may be:

- Towing.
- Widely varying displacement.
- Bottom fouling.

For each design it is suggested that a diagram similar to figure 1 be prepared. Plot the ship's actual speed power curve on the diagram, converting the s.hp. to b.hp. by dividing by the transmission efficiency.

After establishing the speed power curve on a per cent rpm and per cent installed b.h.p. basis, the speed power curve when using half installed engines can be plotted by multiplying the per cent b.hp. for a given per cent rpm by 2.

The diesel engine is considered a constant torque engine and can reach 100 per cent b.m.e.p. at any given rpm above idling speed. However, limitations are imposed to protect the engine from:

- Possibility of insufficient lubricating oil to protect the engine at high b.m.e.p. due to low output on attached pumps at reduced engine rpm.
- Low b.m.e.p. which results in heavy carbon deposits in the engine.

Figure 2 shows the limitations graphically.

By varying the number of engines the best combination can be selected for the particular ship. The cruising conditions should fall in the desired operating area. For relatively high speed ships, this will usually occur when operating with 50 per cent or less of the installed engines. Auxiliary vessels may require a greater percentage of the installed engines operating. After a satisfactory engine combination is selected, and if sufficient data are available, plot the fuel consumption curves for the particular engines being considered over the speed power curves. This results in a complete picture of the performance characteristics of the main propulsion plant (see figure 3).

Using the above prepared data, compute the weight of propulsion fuel required to meet the specified endurance for the ship. To obtain total fuel required, add the auxiliary fuel requirements for generator and boiler to the ship propulsion fuel. This total figure represents the burnable fuel required for endurance.

In determining the fuel required for ship service generators, the electric load should be that determined by power analysis for 24 hours average cruising conditions.

In determining the fuel required for auxiliary boilers, the load on the boilers should include, as applicable:

50 per cent of the ship's design space heating load (intermittent system).

50 per cent of the ship's galley, laundry, and hot water heating loads (constant system).

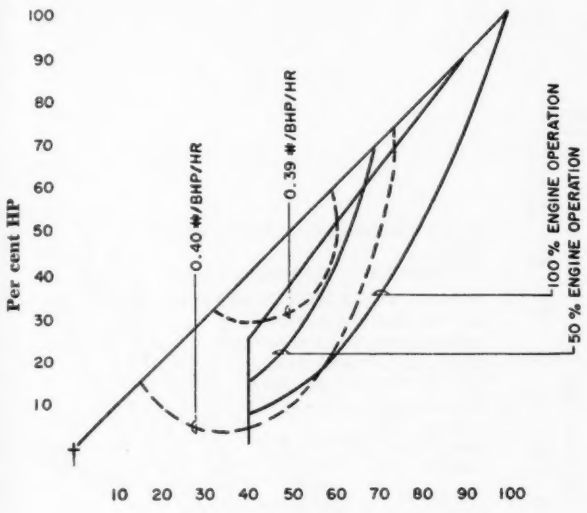


Figure 3

100 per cent of the distilling plant steam requirements.

The following is an example:

f.p. s.hp.	7,600
f.p. speed	20 knots
f.p. rpm	300
cruising speed and endurance	11.7 knots 10,000 miles
cruising rpm	175.5
total b.hp. required	8,000

Speed power curve:

Percent Power	Speed Knots	Percent r.p.m.
100	20	100
80	18.6	92.8
60	16.9	84.4
40	14.7	73.7
20	11.7	58.5
10	9.3	46.4

Assume two-engine installation:

At 58.5 per cent rpm one-engine operation, the

$$\% \text{ b.m.e.p.} = \frac{0.20}{0.585} \times \frac{2}{1} = 0.684 \text{ or } 68.4\% \text{ b.m.e.p.;}$$

which is in the recommended operating area of figure 2. The specific fuel consumption is 0.39 lb. per b.hp. hr. from figure 3.

$0.20 \times 2 \times 2$	= 1600 b.hp. hr.
1600 b.hp. hr. $\times$ 0.39 lb. per b.hp hr.	= 624 lb. hr.
Auxiliary generator	= 170 lb. hr.
Boiler	= 150 lb. hr.
Total	= 944 lb. hr.
$\frac{944 \text{ lb. hr.} \times 10{,}000 \text{ miles}}{2240 \text{ lb. ton} \times 11.7 \text{ knots}}$	= 360.2 tons burnable fuel required

At 58.5 per cent rpm two-engine operation, the

$$\% \text{ b.m.e.p.} = \frac{0.20}{0.585} \times \frac{2}{2} = 0.34.2\% \text{ b.m.e.p., which}$$

is in the recommended operating area of figure 2. The specific fuel consumption is 0.40 lb. per b.hp. hr. from figure 3.

0.20×8000	= 1600 b.hp. hr.
1600 b.hp. hr. $\times$ 0.40 lb. per b.hp. hr.	= 640 lb. hr.
Auxiliary generator	= 170 lb. hr.
Boiler	= 150 lb. hr.
Total	= 960 lb. hr.

$$\frac{960 \text{ lb. hr.} \times 10{,}000 \text{ miles}}{2240 \text{ lb. ton} \times 11.7 \text{ knots}} = 366 \text{ tons burnable fuel required}$$

For this example, a two-engine installation, cruising on one engine, would be recommended in order to permit the more desirable engine operating condition of 68.4% b.m.e.p. as well as the smaller quantity of fuel required.

After arriving at the minimum fuel requirement consistant with good operating procedure the total machinery plant weight is arrived at for each propulsion plant considered.

That plant having the least total weight of machinery plus fuel is usually considered as being the best plant for the ship, this criteria is basic for combatant ship and is the result of a marriage between efficiency of the power plant and the operating efficiency of the ship as a whole. Other factors considered are cost of maintenance, first cost, space, reliability, etc. Any one of these other factors could become the deciding factor in selections of the machinery however, they have a secondary effect on the selection.

Often the endurance requirements of a design are not firmed up during the preliminary design stage and the easiest way to study the design is to solve for the endurance requirement that would result in the same total weight of machinery plus feed when compared to a base plant.

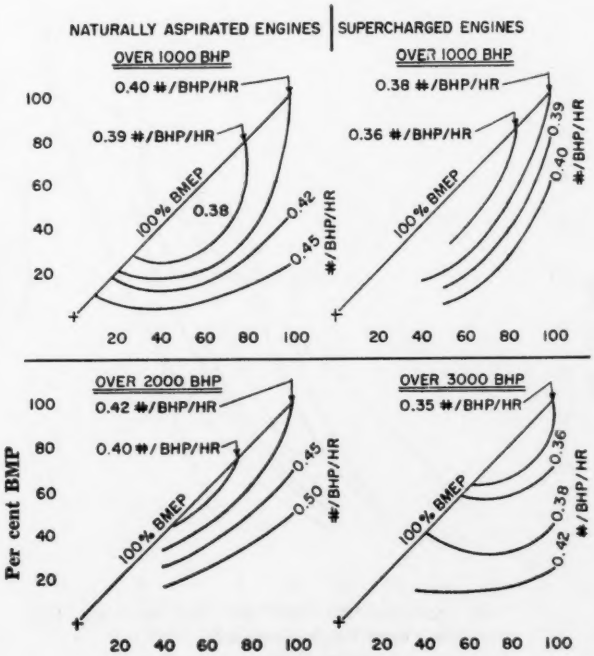


Figure 4

When computing the number of hours (endurance) at which the total weight of machinery plus fuel is equal, and above or below which one or the other has the advantage the following computation can be used:

$$\text{hours} = \frac{100}{\%\ \text{load}} \times \frac{\text{(Specific weight plant A—Specific weight Plant B)}}{\text{(Fuel rate Plant B—Fuel rate Plant A)}}$$

From this sample comparison we can see which plant has the advantage for any given ships endurance characteristics.

Typical fuel rate curves for late model engines are given as figure 4.

Multi engine installation load characteristics based on a cube relationship between power and ship speed and using hydraulic couplings are given in figures 5 and 6.

Bore vs. specific weight relationship is given in figure 7.

Bore vs. BMEP (psi) relationship is given in figure 8.

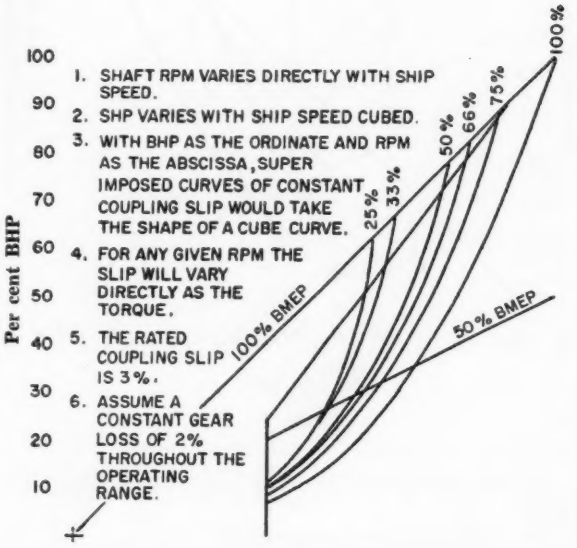
Bore vs. piston speed relationship is given in figure 9.

Bore vs. stroke relationship is given in figure 10.

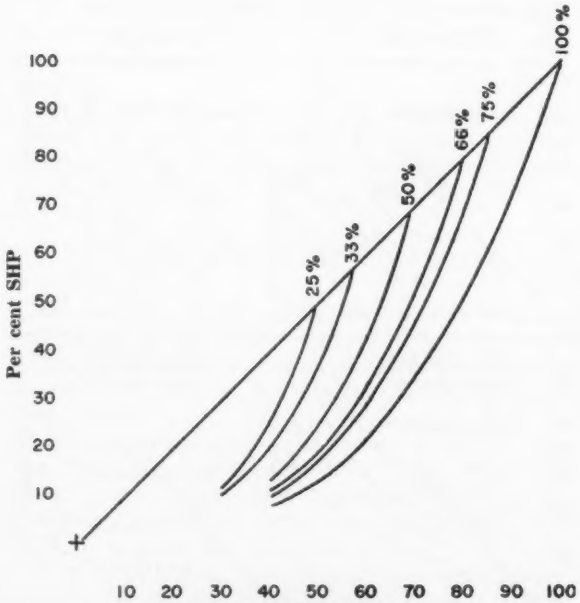
Total displacement vs. specific weight is given in figure 11.

CONCLUSION

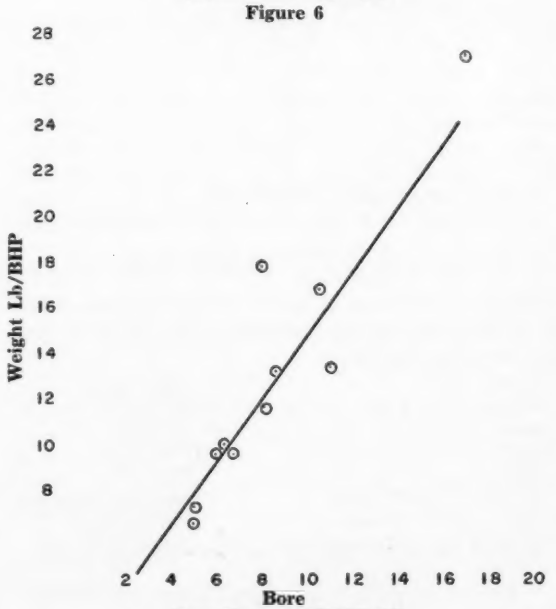
The foregoing discussion of "Selection of diesel propulsion plants for Naval use" was presented in the hope that those concerned with the subject may find it of interest and value.


1. SHAFT RPM VARIES DIRECTLY WITH SHIP SPEED.
2. SHP VARIES WITH SHIP SPEED CUBED.
3. WITH BHP AS THE ORDINATE AND RPM AS THE ABSCISSA, SUPER IMPOSED CURVES OF CONSTANT COUPLING SLIP WOULD TAKE THE SHAPE OF A CUBE CURVE.
4. FOR ANY GIVEN RPM THE SLIP WILL VARY DIRECTLY AS THE TORQUE.
5. THE RATED COUPLING SLIP IS 3%.
6. ASSUME A CONSTANT GEAR LOSS OF 2% THROUGHOUT THE OPERATING RANGE.
100% BMEP
50% BMEP
25%
33%
50%
66%
75%
100%
Per cent BHP
Per cent RPM (Engine)

Per cent of Installed Engines Operation
BHP Vs RPM (Engine)
(Hydraulic Couplings)
Figure 6

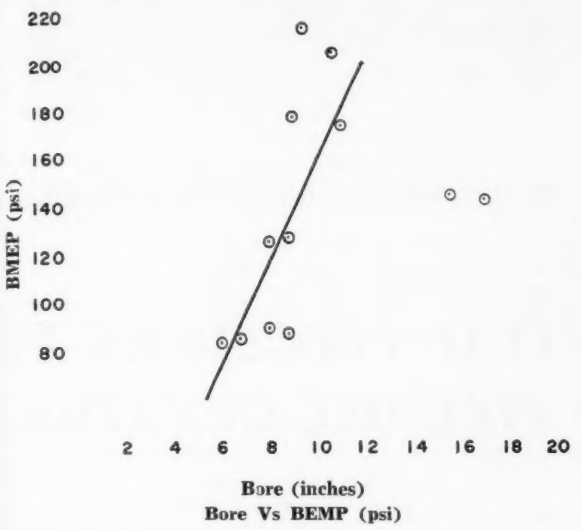


Per cent of Installed Engines Operation
SHP VS VK (Speed)
Figure 5



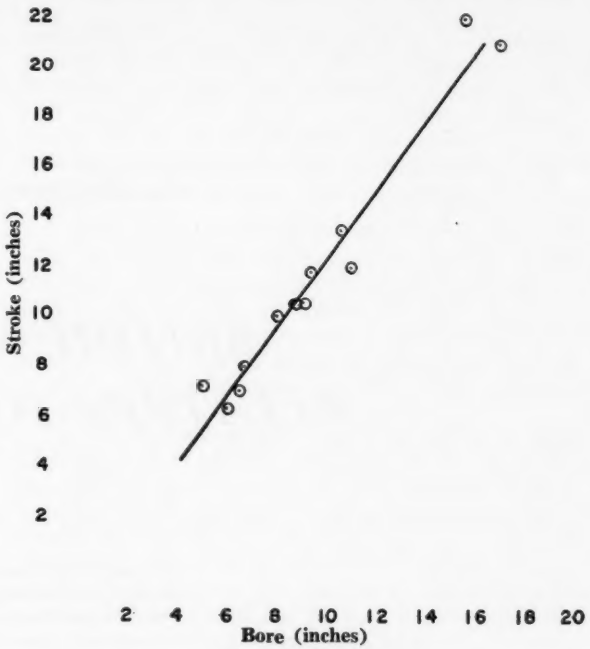
Bore Vs Specific Weight
Figure 7

Note: This curve is based on engines studied by the author in the last year for main propulsion application.



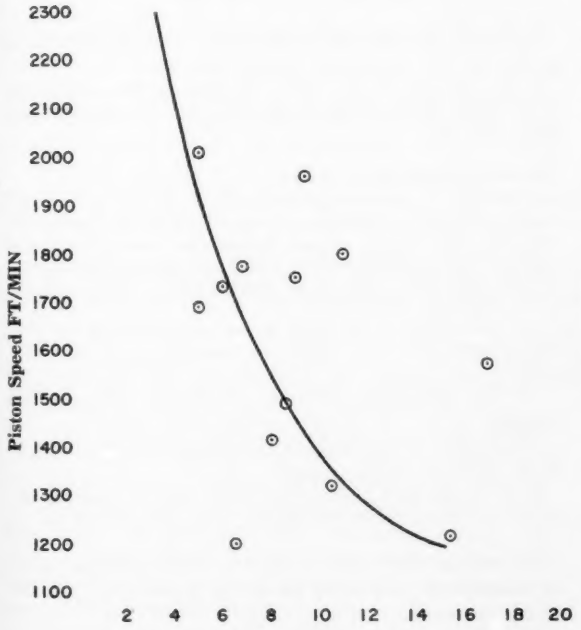
Bore Vs BEMP (psi)

Figure 8



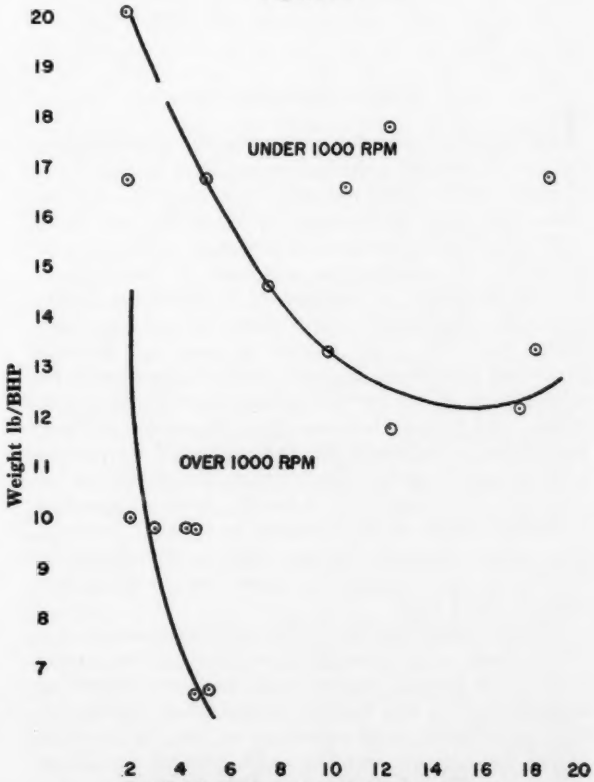
Bore Vs Stroke

Figure 10



Bore Vs Piston Speed

Figure 9



Total Displacement vs Specific Weight

Figure 11

Note: These curves are based on engines studied by the author in the last year for main propulsion application.

"TRANSACTIONS OF THE INSTITUTE OF MARINE ENGINEERS"

BRITISH NAVAL PROCEDURE IN RELATION TO FIRE ORGANIZATION

ACKNOWLEDGEMENT

This paper was one of four contained in a symposium on "Fires in Ships" read before The Institute of Marine Engineers and The Institution of Naval Architects. The authors were L. T. Carter, Royal Corps of Naval Constructors, who is Assistant Director of Naval Construction, Admiralty, and Captain H. C. Hogger, R.N., who is Assistant Engineer-in-Chief, Admiralty. The paper was published in the December 1956 "Transactions of The Institute of Marine Engineers."

GENERAL INTRODUCTION

THIS PAPER is a resumé of the fire fighting organization and methods used to combat fires in the Fleet. It begins with a brief historical survey of fire regulations, and after a reference to losses by fire up to 1939, stresses the lessons learned in the 1939–45 war, quoting some outstanding instances of fire damage. The development of equipment in the light of fire statistics is discussed, with general remarks on basic policy from the point of view of user and stowage problems. Reference is made to the fundamental requirements of fire protection and their influence on design and fittings, followed by a discussion of fixed installations, including the fire main and its pumps, and the special properties of foam. The problems associated with particular hazards such as gasoline stowages, flight decks, hangars in aircraft carriers, etc., are mentioned, together with a description of the fire protection provided, and the problems met with in small craft.

There is a description of first aid equipment in use in the Fleet, with remarks on emergency items such as portable pumps, protective clothing and breathing apparatus. The fire fighting organization within the ship is reviewed, with reference to training facilities at the fire schools and the work carried out at the Admiralty Fire Test Ground. The special requirements of Arcticization are mentioned and there is a brief reference to the steps taken to provide an interchange of fire fighting equipment between N.A.T.O. Navies.

HISTORICAL INTRODUCTION

In 1730, the Navy Regulations and Instructions contained the following order:—

Such as smoke tobacco are to take it in the Forecastle and in no other place, taking all possible care to prevent accidents from fire.

The order then goes on:—

and for further preventing such accidents, care is to be taken every night that immediately upon the setting of the watch, both fire and candle be put out in the cook room, hold, stewards room, cockpit and everywhere between decks, the master-at-arms or some other careful officer being sent out to see the same performed.

Nor are candles to be used in any other part of the ship but in lanthorns.

—or in twentieth century language, No Naked Lights.

A further paragraph in the book, in the instructions for the gunner, reads:—

He is to take care that nobody enters (the powder rooms) with such things about him as may strike fire in falling.

In present-day orders, special shoes must be worn in magazines, and steel tools are prohibited for the same reason.

By Nelson's time, the regulations about Fire had been amplified, and in the "Regulations and Instructions relating to His Majesty's Service at Sea" of 1806, we read:—

(The Captain) is to be extremely attentive in taking every possible precaution to prevent accidents by fire.

He is not to allow any person to smoke tobacco in any other place than the galley.

He is strictly to forbid the sticking of candles against the beams, the sides or any other part of the ship.

He is strictly to inform the officers not to read in bed by the light of either lamps or candles nor to leave any light in their cabins without having some person to attend it.

He is to direct the carpenter to see that the holes in the decks through which the funnels of the stoves are passed are well leaded.

He is to give the most positive orders and most rigorously to enforce them, that spirituous liquors shall not be drawn off or moved from one vessel to another anywhere but on the upper deck and by daylight only. Any lights necessary for the occasion are to be in very good lanthorns and are to be kept as far from the spirits as possible.

From these extracts, it is obvious that our Naval forbears of 150 years ago were fire conscious and with very good reason. The wooden walls of Nelson's day presented an appalling fire risk. Built entirely of wood caulked with oakum and pitch, rigged with hemp and manila and with a prodigious acreage of canvas, the ship itself was highly flammable. There were quantities of spare canvas and cordage carried below, to say nothing of barrels of powder. With no artificial lights but candles, the smoking materials of the crew and rudimentary fire fighting appliances, there is little wonder that fires in warships were frequent and disastrous.

In 1794-1800, for example, there are records of the total loss of six British warships by fire involving the loss of over 1,500 men. These were all accidental fires; enemy action was not involved—it is difficult to discover whether battle casualties were caused by fire or other damage.

Our knowledge of fire fighting equipment of those days is scanty. Ships were fitted with pumps of a primitive type and leather hoses were known, but there is no reference to pumps or hoses being used for fire fighting; it is probable that fire fighting equipment was restricted to buckets and possibly wet blankets or canvas. It was known for the carpenter to be called on to bore holes in the ship's side below the waterline, which must have been a desperate measure.

The coming of steam introduced new fire hazards both from the fuel and the heat sources involved, but the dangers were more than offset by the iron or steel hulls and the fact that for the first time power pumps were available for fire fighting. There is therefore a marked fall in the number of fires during the latter part of the nineteenth century. The introduction of oil fuel into the Royal Navy does not seem to have raised the incidence of fires, possibly because the risk was so obvious that precautions were taken from the start.

Although fire must have been a contributory cause of many ship losses in the First World War, there is no information to show whether it was ever a principal cause. The damage and losses through fire were, to a great extent, overshadowed by the explosion disasters of this period. Although not due to fire in its general sense, these losses were in one respect fire losses in that most of them were caused by the intense heat flash from an exploding projectile penetrating to magazines containing cordite, which in those days was seldom in metal containers. By the end of the war, the danger had been appreciated and flash-tight doors and fittings made a magazine explosion unlikely except as a result of a direct hit.

FIRE LOSS AND DAMAGE IN THE 1939–45 WAR

In the period between the two world wars there were few major fires and not a great deal of progress in Naval fire fighting. The natural drive for economy put a brake on the development or provision of new appliances and the necessity of observing various treaty limitations made the saving of weight a matter of special importance.

During this period there was little change in ship fire fighting arrangements, which were based on the fire main as the principal medium against fire. Steam drenching arrangements for boiler rooms were introduced about 1926 and in 1923 trials were started using foam. The growing numbers of aircraft carriers in the Fleet kept up the interest in fire fighting to some extent, but looking back it is clear that the ships of these years were woefully short of equipment.

It did not need many months of the Second World War to pin point the shortcomings. It is impressive, however, on looking at the reports of ships which suffered fires to see how often the words, "Fire extinguished without difficulty," occur. Even in the early days of the war, such reports were frequent, and bearing in mind the scarcity of equipment, it is apparent that the technique of fire fighting was very quickly learned, and that determination and ship knowledge are quite as important as equipment.

There is, however, a darker side. An accurate assessment of the severity of fire damage in action is impossible. Ships were nearly always damaged in other ways. However, it is estimated that out of the total number of ships sunk, excluding submarines and minor vessels, about 8 per cent were lost primarily because of fire. That is not to say that they were otherwise undamaged, but it is considered that these ships could have been saved had there been no fire. A few examples may indicate some of the lessons that were learned in ship fire fighting in the war.

In 1942, H.M.S. *Arethusa,* a cruiser of 7,000 tons, was struck by a torpedo on the port side forward. The ship took a list of 15 degrees—one can imagine what that means to fire fighters—and an intense fire broke out, enveloping most of the fore superstructure. The fire was nourished by oil blown over the superstructure by the explosion and by paintwork, wooden fittings and clothing. Of the three pumps which were running at the time, two were immediately put out of action by failure of electric supplies; within half-an-hour they were running again. The ship's foam equipment was used until all foam compound was exhausted, and first aid appliances were then brought to bear. The torpedo struck at 6 o'clock

in the evening; the report says simply, "The fire was extinguished by daylight on the following day." In spite of her injuries, H.M.S. *Arethusa* survived largely because of good training in fire fighting. She was certainly not lavishly equipped.

A sterner lesson was learned in H.M.S. *Southampton,* a cruiser of 9,000 tons. At 3.20 p.m. on 11th January 1941 she was struck by two or four 500 lb. bombs. One or two exploded near the forward boiler room just abaft the bridge structure, the others aft near X magazine. Both explosions started fires. The forward fire was soon under control in spite of the fact that only one pump was running and many key men in this area had been killed. The fire aft was never under control. The forward boiler room was out of action and the forward engine room ceased to function. The after engine room, which was intact, had to be evacuated because of the heat of the fire raging above it. The ship was thus left without power. Finally, a further major fire broke out forward due to oil on top of the water in "A" boiler room reaching the hot furnace. This was not noticed until the funnel was red-hot. Eventually, the ship had to be abandoned and sunk by our own forces. Although this ship suffered severe damage, the primary cause of her loss was failure to extinguish the fires.

There were some losses where it is apparent that nothing could have saved the ship.

H.M.S. *Trinidad,* a 9,000 ton cruiser, was torpedoed in the Arctic and limped into Murmansk where temporary repairs were carried out. She then sailed for home and was struck by two bombs almost in the spot in the ship where she had been torpedoed. The explosion started a major fire just abaft the bridge, cut the fire main and killed the whole of one damage control party (a ship of this size would probably have three or four). Because of continuous attacks by torpedo bombers, the ship had to continue steaming at high speed and this fanned the fire through rents in the ship's hull. As a result of the previous damage, the area was full of timber shoring and, in spite of efforts to clear it, was covered in many places with oil fuel blown into inaccessible corners by the previous explosion. The fire parties were greatly hampered by smoke and the 10° list which developed. Eventually, the ship had to be abandoned and sunk by our own forces. In this case, although additional fire fighting equipment might have helped, it is doubtful if anything could have saved the ship.

There is no time to add further examples. It is a depressing tale relieved by glimpses of the courage and tenacity with which innumerable fires were fought. However, by the end of the war the fire losses were considerably reduced. The lessons had been learned, and these lessons were: first, the vital importance of training in all aspects of Damage Control, but particularly fire fighting, and the fact that this training should be done as a team, with men working and learning under the officers and petty officers who will lead them in action. Second, there must be good and adequate equipment well distributed around the ship. Third, with the exception of fuel and ammunition, as far as possible everything that will burn must be kept out of warships. Finally —and perhaps the most important of all—every man must know his ship—this is of importance in all aspects of damage control, but nowhere more than in fire fighting, where dense smoke, wreckage and heavy list may accompany every fire.

THE POST-WAR PERIOD

Since the war, there have fortunately been no catastrophic fires in British warships. This is partly due to the excellence of the fire fighting equipment, which embodies most of the lessons of the war, and within the limitations of weight, space and cost, could probably not be bettered very much by any existing equipment.

An analysis is made and published yearly of all fires that occur in these ships—the causes, effects and methods of extinction used. In 1955, there were 101 fires reported, of which six were classified as major, eight as medium, and eighty-seven as minor. There was no loss of life or serious injury directly attributable to fire. Welding operations were responsible for twenty-one of the fires reported and the disposal of smoking materials came second with seventeen, followed by the breakdown of cable insulation with eleven. In the last ten years, the use of gasoline in the Navy has been virtually eliminated except in aircraft. This is reflected in the fact that only one minor gasoline fire was reported in 1955.

The analyses, so far, have given no indication that the present equipment or methods are wrong. It must be remembered, however, that in war the causes of fires might be very different. Nevertheless, these statistics serve a useful purpose in keeping the danger of fire to the fore and enabling the Admiralty to issue warnings and recommendations to the Fleet of any dangerous trends in fire risk.

FIRE FIGHTING IN THE ROYAL NAVY TODAY—GENERAL CONSIDERATIONS

The modern warship is a most complicated machine and although it is less flammable structurally than its wooden predecessors, it contains more flammable equipment.

Many compartments are packed with electrical equipment or oil-using machinery; electric cables run through every compartment; pipes containing flammable liquids are widespread, and in the lower parts of the ship there are large quantities of fuel oils and high explosives.

Even in peacetime a warship presents a considerable fire risk, while in wartime the danger of fire can never be disregarded. For this reason, the prevention and extinction of fire is regarded as of the greatest importance, and everything possible is done in the provision of equipment and training of personnel.

The Administrative responsibility for fire fighting in the Navy is vested jointly in the Director of Naval

Construction and the Engineer-in-Chief. Of these two departments, the former is responsible for the design and provision of fire fighting appliances and for the use of fire resistant materials, while the latter is responsible for fire fighting methods and for the special training of Engineering Branch ratings who form the bulk of the fire fighting manpower of the Fleet.

The basic policy for fire fighting in the Royal Navy is that it is a matter in which everybody is concerned. This is summarized thus in the Admiralty Ship Fire Fighting Manual:—

> To meet the menace of fire in H.M. Ships, it is essential that all on board should be familiar with the principles of fire extinction and the handling of fire appliances.

There are no professional firemen in a ship; for this reason, fire fighting equipment must be simple to use and maintain. It is important that any man who discovers a fire should be able to pick up the nearest appliance and know that it will work.

The size and weight of the fire fighting equipment is a matter of concern. Also, a warship has to go anywhere in the world, so that it is no use having fire appliances which require a large number of refills of widely differing types and patterns.

The requirements for equipment can therefore be summarized as simplicity of design and operation, ease of maintenance, small dimensions, and the smallest possible number of refills and replacements.

FIRE PROTECTION

Fire protection in a ship involves the provision of fire resistant barriers in the structural arrangements, the elimination of fire causes and the installation of means of detection and extinguishment. It is more than ordinarily important in a ship that a fire, if it occurs, should be contained and extinguished in the space in which it originates. It was in laying emphasis on this aim for passenger ships that the relevant portions of the Regulations of the International Convention for the Safety of Life at Sea, 1948, marked an appreciable advance on the corresponding section of the 1929 Convention. In warships, which are specifically excluded from the scope of the 1948 Regulations, a fire cannot always be restricted to the compartments where it starts. Action damage, for instance, would probably prevent this. As compared with merchant ships, however, warships have the advantage of a closer spacing of main transverse bulkheads and watertight decks, the bulkhead deck is normally the weatherdeck, there is a much greater degree of sub-division, and there is the absence of commodious stairways and long passages. All this is inherent in the purpose for which warships are built, and in practice it adds up to a high degree of fire resistant construction since, generally speaking, the bulkheads and decks are of the standard required for Class "A" and Class "B" divisions as defined in the 1948 Regulations.

It may therefore be said that as regards the provision of fire resistant barriers, the normal structural arrangements in Naval vessels meet requirements, and that emphasis only remains to be placed on fire prevention and the provision of equipment.

FIRE PREVENTION

A warship has to carry a considerable fireload, some of it extremely hazardous, but much can be done in the way of fire prevention by a reduction of flammable materials and by attention to potential risks in the design stage. This aim is steadily pursued although it is not always easy in peace-time when the claims of habitability have to be given greater consideration. Nevertheless, there is today far more fire consciousness than formerly. Generally speaking, the question which is asked when a new material is proposed for use in a ship is "Will it burn?" and, if the answer is "Yes," a search is made for an alternative which preferably will not burn at all, or more usually, which possesses some measure of fire resistance. Where fire hazards cannot be eliminated, an endeavor is made to minimize them by a suitable retardant treatment.

There are many items in a ship susceptible to fire prevention treatment. One of them is paint which, in the past, has constituted a serious fire risk accentuated by the thickness to which it was allowed to accumulate. Fires may spread into an adjoining space due to the spontaneous ignition of vapors from blister in the paintwork, which in turn ignites combustibles in the vicinity. This hazard has been reduced considerably by applying a fire retardant paint for interior use, based on a gum damar medium, to Defense Specification 1114. Samples of paint are tested for fire retardance in accordance with the procedure laid down in Defense Specification 1053.

In H.M. ships, all wood except that specially liable to come in contact with food, and wood spars, derricks and deck planking, and wood in magazines, is given a fire retardant treatment by impregnation. Timber so treated will not propagate a fire nor assist in its development. It will eventually char through, however, if heat is sustained. Wood furniture is only fitted in C.O.'s apartments, in wardrooms and in wardroom anterooms, and is made fire retardant. Elsewhere, furniture is of aluminum. The stuffing is generally of horsehair, which is also given a suitable treatment. The possibilities of foamed plastics or neoprene are being considered for mattresses.

In general, linings are not now fitted to the ship's side. The steelwork is insulated with Navy Board made of resin-bonded glass fiber faced with glass cloth which is impregnated with a phenolic resin. The joints are sealed with a glass cloth tape. Wherever possible, fabrics are given a fire retardant treatment by immersing them in an aqueous solution of borax and boric acid in the proportions of 10 oz. of borax and 8 oz. of boric acid to one gallon of water. As the deposits are soluble in water, reproofing is necessary whenever the material has been laundered or exposed to dampness. Plastic coated fabrics are pretreated by the inclusion of a fire retardant me-

dium, such as antimony oxide, in the plasticizer. Glass wool fabrics have low abrasion resistance and therefore have not been introduced.

Electric cables, at present, are insulated with natural rubber or varnished cambric with a protective sheath of neoprene. This gives protection against small fires. Cables in later ships will be given a more complete protection by means of silicone rubber and glass fiber or tape insulation, again with a neoprene protective sheath.

Good housekeeping plays a part in warships as elsewhere. The disposal, as far as possible, of items such as clothing, bedding, stationery, and personal belongings, in metal lockers with doors secured against shock or blast, helps to lessen the risks of fires.

It is not possible to account fully for all the fire reduction measures in Naval vessels, but enough has been said to indicate that considerable attention is paid to this aspect of fire protection.

THE FIRE MAIN AND ITS PUMPS

In an age which can provide extinguishing media ranging from halogenated hydrocarbons to plain sodium bicarbonate, water still remains the most effective agent in general use for dealing with a fire. In a ship, water is easily obtained and the fire main is the main artery of the fire fighting system in Naval vessels. This is fed by widely distributed centrifugal pumps whose numbers are based on fire fighting requirements, together with those for other essential services such as prewetting, cooling systems and sanitary services. Water requirements for fire fighting take into account the possibility of having to fight major fires and spray a block of magazines concurrently.

Over the years the tendency has been for bigger and better fire mains and smaller and better pumps. In the last war it soon became apparent that pump capacities and fire main pressures were inadequate and that existing jet nozzles absorbed so much water that the concurrent use of a small number led to overall inefficiency of the fire fighting system. Steps were taken to increase the standard working pressure from 50 to 75 lb. per sq. in. by providing higher duty pumps in larger numbers. At the same time the nozzles were reduced in size and, as it had become evident that something more than plain jets was required, ships were also supplied with nozzles which could give either jet or spray.

Fire mains today run to 3½ in. in frigates, and up to 6 in. in large ships, with respective total pump outputs of 160 and 1,500 tons an hour. At the outbreak of war pumps could only be started locally but war experience showed the necessity for a remote control position on the lowest communication deck. War casualties also indicated the need to maintain pressure in the fire main at all times by running some of the pumps continuously. This was at first resisted on the grounds of excessive maintenance and the danger of pumps becoming overheated. However, the latter problem was solved after careful tests by fitting leak-off arrangements which give a constant discharge flow of 4–5 gallons per minute from each pump.

Fire hydrants in ships in 1940 were few and far between. Later ships were more generously equipped on the basis that a fire in any compartment should be capable of being dealt with by a 40-ft. length of hose from each of two hydrants. To achieve conformity with the Shore Fire Service, whose cooperation with ships in ports was often essential, the 2½ in. instantaneous coupling to B.S.S. 336 was adopted in new construction, replacing the bayonet joint connection.

The fire main is generally placed in the ship so that it is given maximum protection from action damage. A number of isolating valves are fitted to minimize the effect of wastage or flooding due to fracture and, in addition, all branches are provided with a shut-off valve fitted close to the main. Pressure gauges are supplied at the junction of the pump risers with the fire main, and in other positions, to serve as an indication to damage control parties of any damage to the main. An early war lesson indicated the necessity for providing a rapid means of bridging damaged sections of the fire main, and bulkhead hose connections at positions well above the waterline were therefore introduced so that this could be achieved by lengths of hose which did not need to be passed through doorways.

The standard working pressure for future carriers and cruisers will be 100 lb. per sq. in. and it is likely that this pressure will be adopted for other ships in view of the contemplated use of eductors for general suction duties. The higher pressure will lead to greater fire fighting efficiency without a marked increase in water consumption since a general purpose nozzle has recently been introduced which has a smaller water capacity than its predecessor. This is an aspect which has to be borne in mind in all ship fire fighting, although generally speaking the greater degree of sub-division in warships as compared with merchant ships is a factor which tends to lessen the risks arising out of loose water. Having provided for high working pressures in fire mains, it becomes another problem to maintain them in face of deterioration of the pumps and piping systems. Maintenance can partially cope with the first, but the second is an ubiquitous marine problem, the solution of which is still being sought. Copper-nickel-iron has been adopted for the piping concerned. This material has a good resistance to impingement attack at acute bends where water velocity increases considerably, and it has a close relationship with the gun metal still used for valves. The possibilities of aluminum bronze are also being investigated. Trials have been undertaken of a system for injecting sodium hypochlorite into fire mains to prevent fouling by animal life, but the associated difficulties may make this method impracticable. It may well be that the ultimate solution will be plastic piping.

At present, pumps supplying the fire main can also serve the suction main via a suction valve chest, but the trend is towards single duty pumps with drowned suctions, and the use of portable pumps to deal with purely pumping problems. This will involve the abolition of self-priming arrangements, and also of the suction main. To cope with the possibility of flooding as the result of action damage, pumps in some ships during the war were made submersible by the incorporation of an air bell, but in view of the increased numbers and the wider distribution it is now felt that this feature is no longer a requirement, with advantage to the weight, space and maintenance aspects. In fact, all recent pump developments have involved smaller and lighter units with improved performance.

For a long time hoses supplied to the Fleet have been of unlined canvas, which has the disadvantage of being liable to damage by abrasion, has a tendency to deteriorate in spite of rot-proofing treatment, and has a fairly high resistance to flow as compared with smooth bore hoses. It has recently been decided to introduce rubber-lined hoses into Naval Service and trials are being carried out on a plastic hose with a P.V.C. cover and lining fused on to a synthetic reinforcing fabric, for which great claims have been made. The standard hose size is 2¾ inches. War experience showed that with a hose of this diameter the very restricted space available for fire fighting below decks made maneuverability extremely difficult and so it was decided to use a 2 in. diameter hose in such congested areas. It is hoped that when the rubber-lined hose is in service, it may be possible to effect an all-round reduction in hose diameters. It is standard practice to stow one or two lengths of hose, according to the size of the ship, at each fire hydrant, the hose being flaked down ready for use, with one end connected to the water supply and the other end fitted with a jet spray nozzle.

FOAM

For dealing with fires involving flammable liquids, foam probably constitutes the most effective extinguishing medium and has been used in H.M. ships since about 1923. At that time it was of the type produced by the chemical reaction between aluminum sulphate and sodium bicarbonate in powder form, when mixed with water. The installations were capable of continuous operation and were supplied with water from the fire main at a pressure of 25 lb. per sq. in.

Early in the war attention was drawn to the superior qualities of mechanical foam, and twin tank generating units were installed in ships which carried gasoline. Their operation, however, was a little complicated, and there were mechanical difficulties, notably through gumming-up of valves in contact with the liquid foam compound. As by this time the value of foam application was being more fully realized, it was decided to introduce equipment on a more lavish scale and to change to the much simpler method of generating it by using foam branch pipes in association with suction pick-up assemblies. There are no moving parts in this system and therefore little maintenance requirements other than washing through after use. The branch pipes are connected to fire hydrants by means of a length of hose.

Mechanical foam is produced by thrashing a mixture of water, foam compound solution and air by means of a pump, or, as is done in the Navy, by turbulently mixing the three constituents in a foam branch pipe. The aerated product consists of about 12 per cent water and 88 per cent air. A gallon of water can be converted to six to eight gallons of foam according to the design of the branch pipe.

The foam compound used in H.M. ships is a protein liquid usually derived from hoof and horn material, or from hydrolized blood. Slaughterhouse refuse is the description euphoniously applied to the basic ingredient. The compound is supplied in 5-gal. or 2-gal. containers, hermetically sealed, and when required is induced into the water stream by means of a short length of suction hose connected to an atmospheric venturi in the waterhead of the branch pipe. The free end of the suction hose has a steel piercer which can be thrust through the top of the drum.

Mechanical foam consists essentially of a homogeneous mass of air-filled bubbles which possess sufficient tenacity to provide a resistant blanket screening the surface of the burning liquid from the heat which radiates from the fire, thus reducing the evolution of the vapors by which the flames are fed. For some time after its introduction, there was some belief that the air content would feed the fire. However, it is recorded that successful tests were carried out with foam filled with oxygen, so no doubt the disbelievers were converted.

Most warships which have a reasonable pumping capacity are supplied with foam branch pipes operating off the fire main. In view of the possibilities of action damage they are required to work satisfactorily at pressures down to 35 lb. per sq. in. Outputs vary according to size, ranging from 350/450 g.p.m. of foam in the type most commonly used to 800 g.p.m. in the case of those intended for use on flight decks of aircraft carriers. A fairly stiff foam, that will stay where it is wanted, is generally required, but in the machinery bilges, which have obstructions, a free-flowing blanket is necessary and this is provided by means of a special branch pipe which generates a sloppy foam with a somewhat higher water content. Like all other fire fighting appliances, when foam branch pipes are needed they are needed quickly. They are therefore supplied on a liberal scale and are sited in positions related to the risks they cover, with the necessary complement of drums of compound. A typical aircraft carrier, for instance, has twenty-eight larger type appliances on the flight deck, fourteen of the same type in the hangar, twenty-six sloppy foam producers for machinery spaces and five of the smaller 350/450 g.p.m. variety

placed around the ship for dealing with flammable liquid fire outside machinery spaces.

SPRAY SYSTEMS

Spray systems are fitted in those compartments in a warship where a severe hazard exists and where an early and overall attack is essential to prevent an incident becoming catastrophic, e.g., magazines, oxygen compartments, gasoline control compartments, flammable stores, spirit rooms and hangars in aircraft carriers.

Some of these compartments, notably magazines, are fitted additionally with flooding arrangements, but the protection so provided is not fully effective until the compartment has been filled. It is required that magazines can be flooded direct from the sea in fifteen minutes with the ship floating at the load waterline, but this is a long time for a fire to rage. Spraying gives immediate protection and its effect on buoyancy and stability is less drastic. Furthermore, it does not necessarily put a magazine out of action. When flooding is carried out, spray valves are, or should be, operated first. Spraying is also a valuable preventive measure in the event of a fire in an adjoining space.

Except in hangars, all spray systems fitted in Naval vessels operate off the fire main and water requirements for this purpose are taken into account when pumping capacity is being determined. Systems are normally non-automatic, the grids being fitted with ½ in. orifice sprinklers, usually spaced 7–9 ft. apart. In magazines, care is taken to ensure that the tops and fronts of stowages can be well wetted as well as bulkheads. Under fire fighting conditions, a pressure at each sprinkler of between 10 and 15 lb. per sq. in. can be realized and this is sufficient to ensure complete coverage throughout the compartment. Control valves can either be operated locally by hand, or remotely by rod gearing and handwheels. In latest ships, spray valves can be operated hydraulically from two remote positions as well as manually at a local position. It is relevant to note that one of the lessons learned in the last war was the danger of fitting aluminum handwheels which were liable to melt if involved in a fire.

With the introduction of more advanced weapons, involving an increase in the combustible carried in the associated magazines, it has been decided to introduce electrically-operated fire detectors, and an automatic spray system in the spaces concerned. The detection system selected is based on rate of rise of temperature, and as soon as a detector functions a relay causes the solenoid spray valve to open.

Spray systems, except those fitted in hangars, are dependent on the fire main and this could be a serious disadvantage in the event of action damage. There seems no easy way out of this difficulty, but some work has been done on a scheme for spraying magazines sited low down in the ship, direct from the sea. It has been demonstrated that with heads of water as low as 4 feet, spraying requirements can be met provided an efficient means of distributing the water can be devised. The obvious advantage of direct sea spray is the unlimited availability of water, although problems of heel and trim in damage conditions would clearly have to be considered when defining the minimum head acceptable in the intact condition.

Automatically-operated spray arrangements are fitted in the passenger accommodation spaces of the Royal Yacht *Britannia*. The system is similar in all respects to that fitted in passenger ships. The sprinkler heads are of the quartzoid bulb type. The bulb is frangible and is nearly filled with a highly expansible liquid. When fire occurs, the heat causes the liquid to expand, shattering the bulb and releasing a valve, thus allowing the water to pass. Systems such as these contain water right up to the sprinkler. Initial water supplies are from a tank containing about 500 gallons of water pressurized with air to 100 lb. per sq. in. As the water level in the tank drops, a centrifugal pump taking suction from the sea automatically cuts in. A feature of the automatic system as fitted in *Britannia* is that only those sprinkler heads affected by the fire are operated. Sprinkler systems of this type are essentially first-aid appliances, the aim being to deal with a fire in its very early stage.

MACHINERY SPACES

The problem of fire fighting and fire prevention in the machinery spaces of most warships only differs in degree from that in other vessels. Warships' machinery spaces differ from those in merchant vessels in that they are more congested, which makes the location and extinction of a fire an exceedingly awkward business.

Even in a congested engine room a fire probably starts in a small way, so first-aid fire fighting appliances are kept handy. These are two-gallon foam extinguishers fitted with short hoses because of the probability that fires will be inaccessible.

There are fire hydrants in all main machinery spaces and hoses attached to them. Since fires in these compartments are always likely to involve oil, a special branch pipe is provided which gives a spray only.

With this equipment it is considered that all but very large fires can be extinguished. Machinery space fires can very rapidly become uncontrollable by ordinary means, so further arrangements are made by which the fire can be fought after the compartment has been evacuated.

In every machinery space, tubes are built into the structure, extending from the deck at the crown of the compartment or thereabouts down to about 4 feet from the bilge. Four tubes roughly at the corners are normally fitted to a large compartment and one or two in a small one. If the compartment has to be exacuated, foam can be poured down these tubes, using the ship's main foam appliances until the compartment is almost filled with foam—it would, of

course, be expected that the fire would be out long before this. The tubes are directed against a bulkhead or other flat surface at the bottom and holes are left at the top to allow the foam to escape if the bottom of the tube is submerged.

The second major appliance is a steam drenching system, by which steam can be distributed over the machinery space through open-ended pipes near the crown of the compartment. The valves for operating this system are outside or just inside the compartment.

Arrangements are also fitted for shutting off the fuel supply to the boilers from outside the compartment.

A new problem has arisen with the advent of boilers totally enclosed in their own air casings. It has always been well known that the area under a boiler presented a particularly acute fire risk—especially if, as sometimes happens, a certain amount of oil accumulates there. With enclosed boilers, this fire is inaccessible and could easily damage boiler casings seriously before it could be reached. Ships with this type of boiler are now having a permanent fixed foam installation fitted in the boiler room which will discharge foam into the air casing of the boiler through a fixed pipe system. The extra weight and space is regarded as justified for such a potent source of trouble.

The foregoing arrangements are designed for steam-driven ships with oil-fired boilers. Until recently, the Navy had few Diesel-driven ships except submarines, but with the introduction of Diesel-driven surface warships and possibly of gas turbine ships, it has been necessary to seek an alternative to steam drenching. The first-aid and major foam arrangements remain as they are.

With a certain amount of reluctance, it has been decided that Diesel ships must have a CO_2 drenching system. The reluctance is not due to the medium itself—there is no finer non-toxic extinguishant than CO_2, but this has the disadvantage of being a one shot system. It could be made a two-or-more shot by having more bottles, but the weight cannot be accepted.

The CO_2 system has not been made automatic nor is it allied to an automatic alarm, because the machinery spaces are frequently patrolled when not in use and automatic devices are open to failure in action or under the effect of underwater explosions, or even the ship's own gunfire.

The question of automatic alarms has been reconsidered recently because the machinery in new construction is designed for operation from a remote machinery control room. However, this is really a battle arrangement and, although it will also be used in peacetime, the engine room will then be patrolled, if not actually occupied. In action, the machinery spaces may be deserted for some time, but there will be small windows for visual inspection and a complicated system of alarms does not seem to be justified.

FIRE FIGHTING IN SMALL CRAFT

The large numbers of small vessels in the modern Navy have their special problems. Many craft are driven by machinery using high octane gasoline and they are frequently constructed of wood or other combustible material. Weight and space limitations are particularly severe.

Practically all our small craft are fitted with a fixed installation using methyl bromide. A typical layout consists of four 24-lb. cylinders of compressed gas communicating with pipes led to the engine room and the gasoline tank compartment and arranged for remote operation from the entrance to the compartment and from the bridge.

Because of its toxicity, methyl bromide is being replaced, in the same installation, by chlorobromomethane mixed with 20 per cent freon.

Although CB/freon is safer than methyl bromide, it is still toxic on a fire. Investigations are in progress to evaluate the use of dry chemicals on small ship fires. It is certainly effective on the fire—it also stops the engines.

Closely allied to the problem of small ship fire fighting is that of submarines, where the outstanding feature of fire fighting is that in every compartment there is electrical apparatus which is vital to the existence of the ship. Gas water extinguishers are provided for first-aid fire fighting and specially insulated hand foam extinguishers are available for dealing with small oil fires.

In anything approaching a major conflagration, the most effective measure is to seal the compartment and smother the fire—this is, of course, much easier in a submarine than in any other ship.

A major fire in a submarine is not very probable. The men in the vessel are working, living and sleeping in every compartment and it is almost impossible for an outbreak to be undetected. In action, for obvious reasons, fire is less likely than flood.

SPECIAL HAZARDS

Avgas Stowages

Avgas, or gasoline, is one of the most dangerous flammable liquids in general commercial use and constitutes a special hazard when carried in a ship. The flashpoint, the temperature at which the liquid gives off sufficient vapor to form an ignitible mixture with air, is always well below normal ambient temperature. The vapor is much heavier than air and may flow or drift a long way from the liquid source, and if the train of vapor encounters a flame or other form of heat a flashback will occur resulting in the ignition of the liquid source with, possibly, an explosion. It must be realized that a cupful of gasoline has the potential explosive effect of 5 lb. of dynamite; that one gallon yields about 25 cu. ft. of pure vapor, which is sufficient to produce nearly 2,000 cu. ft. of a flammable mixture; and that the optimum concentration will give an explosive force of 120 lb. per. sq. in. The catastrophic possibilities of an inci-

dent in a ship involving gasoline can readily be imagined. Unfortunately, in spite of every care and attention to detail in handling and stowage, incidents do occur from time to time. During the war, every navy suffered loss directly attributable to damage to gasoline stowages. So far as the Royal Navy is concerned, it is a happy thought that the introduction of jet aircraft using kerosene as fuel will mean a very great reduction in shipboard hazards. However, since the turnover to jets is not yet complete, the risks associated with gasoline must continue to be met.

Stowage of gasoline in warships is mainly restricted to aircraft carriers but there are some other vessels, such as surveying ships and landing craft, which are required to carry this fuel in bulk. Until recently, the stowage in carriers consisted of drum type tanks fitted in the fore end of the ship below water level, piping connections being made flexible enough to allow for a certain amount of vertical movement as a result of shock. These gasoline compartments were not in the first place kept filled with water, but as a result of an explosion in 1936 in the Italian cruiser *Goritza*, which carried drum tanks of gasoline in the fore peak, it was decided to keep them permanently flooded in wartime. This later became peacetime practice. To meet operational requirements for an increased stowage of gasoline, bulk stowage has now been adopted, with welded tanks forming part of the ship's structure. Surrounding each tank is a ventilated cofferdam fitted with a number of small bore tubes through which samples of its atmosphere can be drawn for test by explosimeter. Cofferdams can, in an emergency, be flooded direct from the sea. Ventilation is by fan exhaust and natural supply, with duplicate exhaust fans each having sufficient capacity to give twelve changes of air per hour. It is interesting to note that the Joint Committee on Fire Grading of Buildings which recently investigated the precautions necessary against fire and explosion in underground car parks, recorded that the lower limit of flammability would not be reached until 100 per cent of the floor area was covered with gasoline, provided the ventilation was at the rate of ten changes per hour.

An alternative method of protection by inerting the cofferdam with the nitrogen by-product from the oxygen-producing plant in the ship has been considered. This, however, involves complicated and vulnerable instruments for the detection of gasoline vapor in such an atmosphere and for the determination of the degree of inertness provided.

Although the ventilation method is thought to be slightly less positive than inerting, its simplicity is greatly in its favor, and it is therefore likely to be retained in H.M. ships, especially in view of the diminishing requirements for gasoline stowage.

Air driven portable pumps and fans are supplied to clear away liquid gasoline or gasoline vapor in compartments affected by action damage involving gasoline stowages. The pumps weigh only 56 lb. and, when operated at an air pressure of 80 lb. per sq. in., each will deliver 140 gallons per minute through 50 feet of hose to a height of 40 feet, with correspondingly greater outputs at a reduced lift. The pumps and fans are operated from the l.p. air system.

Flight Decks

Flying operations off a carrier involve, in peace as well as in war, the possibility of an aircraft crash fire. Fortunately, such incidents do not happen very frequently and there is reason to believe that in the future they will become even less frequent as a result of the introduction of the angled flight deck. Nevertheless, when they do occur, the safety of the ship may be endangered. Training and drills are based on the rescue of the pilot as being the primary object, and this is subordinate to fire fighting only when the safety of the ship is involved by reason of the spread of fire or by the presence of explosives in a fire. It is essential that aircraft crash fires be dealt with quickly and effectively and considerable attention has been paid to the improvement of flight deck fire fighting arrangements.

In older carriers, flight deck hydrant pressures are, generally speaking, low. Water supplies in these vessels are taken from the ship's fire main; when this is new and with the pumps working at full speed and all extraneous services shut down, a reasonable pressure of 50–55 lb. per sq. in. can be realized. In practice, however, pumps are seldom run at full speed, domestic and other requirements from the fire main fluctuate considerably, and the fire main system, including the pumps, tends to deteriorate in efficiency. Pressure at flight deck hydrants therefore tends to be low, often approaching the minimum necessary for the satisfactory operation of foam branch pipes. The latest carriers will have a special flight deck fire main not connected to the ship's fire main or any other service, and supplied by three or four independent pumps used for no other purpose and capable of giving 100–110 lb. per sq. in. at flight deck hydrants. It is intended to use an inline inductor at each hydrant, the loss of pressure across it being acceptable since 60–70 lb. per sq. in. will still be available at the branch pipe.

Hydrants on flight decks are sited at 60 ft. intervals at each side of the ship, to give ample coverage. They are fitted in convenient positions in walkways and in the vicinity of the island, together with the associated hoses, foam branch pipes and drums of foam compound. In existing carriers, where the foam compound is induced at a branch pipe on the end of a line of hose, the drums of compound must be trundled across the deck. In carriers fitted with inline inductors, the drums of foam compound will remain at the hydrant position, the compound itself being induced by means of a short length of suction hose connected to the inductor.

The branch pipes in older carriers produce 800 g.p.m. of foam. With the increased pressures available in vessels fitted with the separate flight deck fire main, it will be possible to introduce an improved

appliance generating 1,050/1,100 g.p.m., with the added advantage of a special flaking device by means of which a snowfall effect can be produced, as well as the normal jet. Directing jets against the fuselage of a burning aircraft leads to a considerable run off. The flaker will, if conditions are right for its use, help to conserve foam by ensuring that most of it falls on the fire.

It is usually reckoned that about 45 seconds is the maximum time available in which to rescue a pilot from an aircraft crash fire. Until recently, rescue equipment consisted of a wheeled unit carrying a 40-lb. cylinder of CO_2 at 850 lb. per sq. in. The gas provided protection to the rescue personnel. For some time, however, it has been thought that CO_2 was not the best medium for the purpose and carriers have now been equipped with mobile units, each containing 150 lb. of dry chemical which can be discharged through a 50-ft. length of hose by compressed CO_2. The standard dry chemical is sodium bicarbonate, although other and, reputedly, more effective powders are available. A cloud of powder discharged under pressure has a remarkable extinguishing effect and also provides excellent protection from the heat of the fire to the personnel operating the unit.

Hangars

In Naval phraseology, hangars are known as dangerous areas. They are more or less enclosed spaces with center line elevators, in most carriers, for taking aircraft up to the flight deck. Elevators are normally fitted with gas seals. A gasoline fueling line runs on each side of the hangar with fueling points at intervals. Except when aircraft are being fueled or defueled, the lines are empty, but during fueling operations with the lines under pressure and aircraft tanks full, there is always the possibility that leakage or spillage of gasoline or gasoline vapor may occur. Every precaution is obviously taken to avoid the presence of a source of ignition.

During fueling or defueling, aircraft are bonded to the deck, and the special hoses for the purpose are bonded to the aircraft. In order to provide suitable facilities for maintenance work in hangars, two security conditions are observed, (i) Fuel Danger State, and (ii) Fuel Stowed State. Generally speaking, the Fuel Danger State is proclaimed during fueling and defueling, when spraying with dope, if a leakage has been discovered, or if fuel has been spilled. There is not scope in this brief resumé to remark on the full nature of the precautions taken or the relaxations where risks can safely be localized. However, they do cover especially the use of electric circuits over 15 volts below a 5-ft. level, electric tools of all kinds, portable electric lights other than flameproof types, and a wide variety of hand tools. All these are prohibited when the hangar is in the Fuel Danger State. In the Fuel Stowed State, the restrictions are removed, provided full normal ventilation is maintained.

Hangars are kept well ventilated at the rate of twelve changes of air per hour, with forced exhaust and natural supply. The system is separate from the ventilation of any other part of the ship. Fans are fitted with flameproof motors and special arrangements are made to prevent sparking in the event of fan rotor blades touching the casing. It is general experience that under normal ventilated conditions there is little danger of gasoline vapor collecting in explosive quantities. The last reported instance of an incident in a hangar arising from gasoline was in 1946.

All the foregoing relates to fire prevention, which is the basis of all fire protection. Should an incident occur, however, equipment to combat it is well disposed about the hangar. Fire hydrants are spaced port and starboard, usually with double hose connections. At each hydrant is stowed a large-size foam branch pipe, drums of foam compound, an 80-ft. length of hose and a jet spray nozzle.

A spray system is also fitted in the crown of the compartment, consisting of a series of non-automatic ½-in. flat star sprinklers arranged 10–12 feet apart. The sprinklers are supplied through a suitable piping system by three or four single-speed centrifugal pumps sited below the waterline. The pumps can be operated by switches in each hangar access lobby and from a Hangar Control Position. Spray valves are operated by large handwheels in the access lobbies. The capacity and delivery pressure of the pumps is such that any two sections of a hangar can be sprayed concurrently with an average sprinkler flow pressure of about 15 lb. per sq. in.

Essential features associated with the hangar spray system are the fire curtains and the scuppers. The fire curtains are of reinforced asbestos cloth and can be either hand- or power-operated. They divide the whole hangar into sections 120–160 feet long. Their function is to afford a firebreak and also to reduce the air supply to a fire. At one time, the fire curtains were roller shutters made of steel slats, but war experience showed that an explosion in a hangar could disintegrate the slats, and cases were reported of serious casualties to personnel due to flying fragments. Asbestos curtains are not susceptible to this hazard and also respond more easily without being damaged to changes in atmospheric pressure when spray is used on a fire.

Adequate scuppers are fitted in view of the large area which can become flooded. In order that they can function adequately, they are provided with long perforated covers as a protection against choking by debris.

FIRST-AID EQUIPMENT

Shakespeare said that a little fire is quickly trodden out, which being suffered rivers cannot quench. On a lower level of phraseology, most fires if tackled at once can be dealt with by hand appliances, if these are available, together with personnel trained in their use. It is the aim in H.M. ships to provide both these requirements. Neither of these, however, was

conspicuously present in the Fleet of 1939. There were chemical foam extinguishers in boiler rooms and a few carbon tetrachloride appliances for wireless rooms. Elsewhere there were buckets of water, but these, although useful, were inadequate for coping with the many small fires which so often followed a shell or bomb explosion.

The position was radically altered by introducing a water-type portable extinguisher into the Service in sufficient numbers to provide good distribution and by increasing the allowances of those types already in use.

In the Fleet today foam-type extinguishers are supplied to cover flammable liquid risks, water-type for carbonaceous fires and CO_2 for electrical fires. This is more or less in accord with practice in merchant ships.

Numbers supplied are based strictly on requirements, without over-elaboration, since main equipment is readily available to back up the first attack. Table I gives examples of the scale of supply.

TABLE I

	Foam	Water	CO_2
Destroyer or frigate	23	20	18
Cruiser	35	60	30
Carrier	90	120	52

No piece of equipment is accepted for use in the Fleet without undergoing extensive trials at the Admiralty Fire Test Ground at Haslar. Although there has been no marked change in design of portable extinguishers for several years, considerable work is now being carried out by various commercial interests on the development of new types.

PORTABLE FIRE PUMPS

Early in the war it became clear that there was an urgent requirement for a self-contained pump for fire fighting. Before 1939, the only portable pumps carried in warships were a small motor-driven reciprocating pump of 5 tons per hour capacity, and an electric submersible of 50 tons per hour capacity. The first was too small for most purposes and the second very heavy.

Both these pumps suffered from being electrically driven; if the ship lost power they were therefore useless and at this time there were many ships in service which had only steam-driven generators. Damage to the steam installation in one of these ships, if it started a fire, could cause the loss of the vessel from fire alone, since without steam no pumping capacity was available.

There is, moreover, in war—and indeed in peace—a fairly frequent demand for a fire pump to be sent to another ship, or away in a boat as an improvised fire float, or to be landed for fire fighting or salvage work, and for any of these duties the prewar pumps were useless.

It was therefore agreed that a self-contained pump must be provided and, as it was necessary to do away as far as possible with gasoline engines, it was inevitable that the new fire pump should be Diesel-driven. The pump selected was two cylinder Diesel-driven, with a capacity of 27 tons per hour at about 50 lb. per sq. in. discharge pressure. It has proved to be robust and reliable and well up to its work. Ashore and afloat it has extinguished fires and pumped out floods all over the world, and practically every ship in the Royal Navy from frigates upwards has at least one of these pumps. Its serious disadvantage is in its weight and size. It weighs 625 lb. and is about 4 ft. 6 in. x 2 ft. 6 in x 2 ft. 3 in. It is difficult to manhandle between decks—almost impossible if the ship is listing—and with the increasing congestion of the modern warship, it is virtually immobile unless stowed on the upper deck.

The Diesel pumps are to some extent restricted by their suction hoses. Unless the ship is stopped, it is difficult to obtain a suction over the side and therefore internal standpipes are fitted at various points about the ship. There are a fair number of these, but it may not be possible to concentrate all the pumps in one area. Sufficient hoses are provided to lead the exhaust gases to a convenient opening.

As a last resort, most small ships are provided with a two-man manual pump capable of operating one quarter inch nozzle at 30 lb. per sq. in., principally intended for use with an FB(O) foam-making branch pipe. This pump is readily portable and can be used anywhere provided the suction lift is not more than about 10 feet.

As a result of complaints from sea about the weight and clumsiness of the Diesel fire pump, efforts are being made to find a substitute. A Diesel pump weighing about 400 lb. looks the most promising and is undergoing trials at present. It is unfortunate that because of the fuel fire risk, use cannot be made of the many light and efficient gasoline-driven pumps available. As a second string, trials are being started of a gas-turbine-driven pump, which only weighs about 200 lb. and the containing cradle is 2 ft. 10 in. long x 1 ft. 9 in. wide x 2 ft. 2 in. deep. It has an output of 150 tons per hr. at 100 lb. per sq. in. and is simple to start and run; but it has two disadvantages —the noise, which is probably acceptable in emergency, and the exhaust gases, which are not. The simple exhaust hose solution is impossible because of the temperature. The possibility of cooling the exhaust sufficiently to make a hose practicable is being examined.

A development which has rendered portable pumps of less vital importance is that in many new construction ships at least one of the ship's Diesel generators is fitted outside the main machinery compartments. This means that a total loss of electric power is much less likely and there would seem to be a case for a reduction in the number of pumps carried. The Diesel pumps cannot all be got rid of because experience has shown their value for use outside the ship—indeed, they have been used much more for this than inboard.

PERSONAL EQUIPMENT

During the last seventy years, much thought has been given to the personal protection of men engaged in ship fire fighting. The object was to devise a garment easy to put on and wear, which would enable a man to approach sufficiently close to a fire to have the best chance of putting it out. It is not intended in ship fire fighting that a man should be able to go into the flames. After many trials and experiments, nothing has been found better than fearnought, a type of very heavy white woolen cloth, usually in the form of a loose jacket and trousers. It is durable, easy to stow; it can be worn, with some discomfort, for quite long periods and it is cheap. It gives good protection in a fire and although it will char, it burns with difficulty, especially if given a fire retardant treatment.

Fearnought gauntlets are worn with this suit. Special anti-flash gear consisting of a steel helmet and hood is supplied for protection from flash burns in action, and this equipment is also used for fire fighting. The equipment can be worn over the salvus or smoke mask facepiece.

Practically every fire in a warship is accompanied by very dense smoke, usually black, which no light will penetrate. Although various forms of emergency and portable lighting are available, men in fire parties must therefore be trained to move around in darkness. Ship knowledge is invaluable.

In addition to obscuring the vision, the dense smoke makes breathing difficult or impossible. Warships are provided with two sorts of breathing apparatus; the salvus—a self-contained oxygen set—and the smoke mask, which is a service anti-gas respirator facepiece attached to a long tube which can be led away from the smoke to a clear atmosphere.

The salvus is a first-class piece of equipment, comfortable to use and with a good endurance. Unfortunately, it is not very easy to operate and requires a trained wearer. For this reason a compressed air breathing apparatus is being developed which, it is hoped, will be simple to wear and have a fairly good endurance. Logistically, it will be an improvement, since refills of air are available wherever there is a compressor.

The smoke mask has recently been modified by replacing the facepiece with one similar to that used by shallow water divers and it is hoped that this will give better vision.

One refinement of the smoke mask is that in ships with l.p. air supplies, a connection is provided in the boiler and engine rooms to enable men on watch to connect their facepiece to this air supply and continue their work even though the boiler room is full of smoke. This arrangement was provided after several boiler rooms had to be abandoned due to smoke, although caused by a comparatively minor fire elsewhere in the ship. In most existing boiler rooms, of course, it is impossible to shut off the air from the fans as this is also the combustion air.

Training men in the use of breathing apparatus and smoke masks can best be done in their own ships. A popular method is to arrange a suitable obstacle course and then put the victims in the salvus or smoke mask with the eyepiece blacked out. This gives the wearer practice in feeling his way around, while his instructor can prevent him from coming to any harm. It is also vastly entertaining to the onlookers.

SHIP ORGANIZATION

It will be simplest to give a brief outline of the action arrangements and then deal with the peacetime sea and harbor arrangements. The organization of a ship varies considerably from vessel to vessel—and sometimes from captain to captain—so the following description should be regarded merely as typical.

The fire fighting organization of a warship in war is part of the Damage Control Organization, which is only one factor of the A.B.C.D. organization. This title stands for Atomic, Biological, Chemical and Damage Control and embraces all aspects of the ship's activities which are purely defensive.

The Executive Officer (second in command) is responsible to the captain for the overall efficiency of the A.B.C.D. organization, but since he cannot give personal attention to the details, a specially trained A.B.C.D. officer is appointed to ships larger than destroyers.

In action, the A.B.C.D. officer is stationed in a central headquarters where he can be informed of, and control, any damage that may occur. For convenience, the ship, depending on its size, is divided into a number of sections for A.B.C.D. purposes. Each section is under the general charge of a junior officer, usually, but not necessarily, an engineer. This officer will have a number of Chief and Petty Officers and other ratings who collectively form the fire and repair parties. These ratings are primarily men of the Engineering Branch not actually on watch below, with a leavening of men from other branches. Very few seamen are included in fire and repair parties because the seamen complement is based on the numbers required to man the armament.

The numbers in this organization vary considerably, but in a medium-size cruiser with a war complement, one would expect the A.B.C.D. organization to be divided into three sections. Each section would probably have two or three fire parties, each composed of a Petty Officer and about six men.

At action stations, the fire parties are spread around the ship at fire posts, which have telephones and a locker containing various fire fighting gear. Continuous patrols, each consisting of two men, are sent out so that every part of the ship is frequently visited to ensure that no damage or fire remains undetected. If a fire is discovered, one man starts work on it while the other reports it to his fire post by telephone or other means. The fire is immediately reported to the section base where the section officer is stationed. The P.O. in charge of the fire party will

meanwhile have taken his party to the fire and commenced operations. Should he need help, his section officer will provide it from other parties. The A.B.C.D. officer in Headquarters is kept informed of progress and if the situation calls for it he may arrange help from other sections, or, in great emergency, even from the crews of disengaged armament.

The whole organization is based on flexibility, and through the Headquarters the fire fighting effort—or any other part of the organization—can be switched rapidly from one incident to another.

Although this organization is for action, it is always available, and even in peacetime if a dangerous fire develops, it is open to the captain to call his ship's company to the action state and then deal with the emergency as if it were action damage.

Fortunately, a major fire in peacetime is a rare occurrence and it would be an unacceptable waste of effort if every time a small fire was discovered the ship went to action stations. A peacetime organization of fire parties is therefore built up which are designed to cover all the various states in which a ship can find herself, from being half demolished in dockyard hands to giving a children's party for five hundred guests in New York. Flexibility is, of course, essential.

The peacetime arrangements for fire fighting in harbor are based on the duty watch. Since leave is normally given to three-quarters of the ship's company each night, the watches are divided into a duty and non-duty part of the watch. It is the duty part which provides the Emergency Party. The Emergency Party will include the fire party and is under the control of the officer of the watch. The Emergency Party consists of ratings of all branches and is exercised daily at 5 p.m. At this exercise, members of the fire party produce all the equipment required for fighting fires and the necessary keys for obtaining access to locked compartments and magazine spraying and flooding valves. Various members of the party are told to work the equipment and to find their way to unfamiliar places in the ship. The Emergency Party exercise today is taken very seriously, and the most exacting Commander will overlook a little damaged paintwork if he knows his Emergency Party can rig a portable pump on the forecastle in a shorter time than anyone else in the squadron. The Engineer Officer of the day always attends when the Emergency Party is exercised.

It is, of course, very important that the daily fire exercise should not be allowed to become a matter of routine and a good deal of imagination is required to ensure that it is not the same old "Fire in the galley" every night. Such imagination is usually forthcoming, although at the end of a long commission one is apt in the search for something new to find the Emergency Party carrying out some highly improbable evolutions.

The Emergency Party are not kept up all night; they sleep in a special place where they are readily on call.

At sea, in peacetime, the procedure varies fairly widely. In larger ships, a skeleton A.B.C.D. organization is frequently kept in being; in smaller ships there may be a variation of the Emergency Party routine.

Records show that an unduly large proportion of fires in warships occur when they are undergoing repairs with workmen on board. In addition to a relatively high smoking risk, there is the acute danger from electric and oxy-acetylene welding. In spite of repeated warnings and innumerable orders on the subject, welding is still one of the worst fire enemies. Ships' officers must be told of any welding operations on board. Welding on obviously dangerous bulkheads is forbidden. Welders and ship's company are told to ensure that both sides of a bulkhead are safe before welding starts and everybody is warned about the danger of sparks on combustibles such as rags, etc. Still fires happen.

TRAINING

Every officer and rating receives during his initial training a short course in the basic principles of A.B.C.D., including fire fighting. Of necessity, this training is elementary and must be backed up by ship training at the earliest opportunity. It is impossible to over-emphasize the importance of training men in their own ship under their own senior ratings. Ship knowledge is all-important. Most men can be taught in a few minutes how to put out quite a large fire in a tray in the open with extinguishers ready at hand. To extinguish a much smaller fire in some inaccessible part of a congested warship is a very different thing unless men are thoroughly familiar with the ship and its equipment.

In order that men shall gain confidence in their equipment, fire fighting schools exist in the major ports at home and abroad. The schools are as near to dockyards as possible so that complete teams from ships can go to them for training. Courses consist of a preliminary one-day course for beginners and an advanced course for the more expert. In addition, ships' fire parties are encouraged to use the fire schools for refresher courses. These are also included in the syllabus of the various Damage Control Courses.

The fire fighting schools have a dummy ship section and large and small pits for fighting various fires.

The principal A.B.C.D. training establishment is at Portsmouth. The fire fighting section is equipped with a two-decked dummy ship section in which fire fighting can be practiced under conditions of realism. There are various pits, including one of over 800 square feet for fighting large oil fires using major appliances, and a number of installations for fighting specialized fires, of which the most impressive is a simulated fish fryer.

There are also lecture rooms and sheds for instruction in every aspect of the subject. Visual aids and films are extensively used, but above all everybody under instruction actually fights the fires. In

addition to Naval personnel, the fire school at Portsmouth has given instructions to a number of civilian fire officers, members of N.A.T.O. and other foreign navies, and to hundreds of officers of the Merchant Navy.

Some instruction in aircraft fire fighting is given at fire fighting schools, but the Fleet Air Arm has its own fire fighting section in the School of Aircraft Handlers at Gosport, where instruction is given in the technique of aircraft fire fighting ashore and afloat. Although strictly the subject is outside the scope of this paper, it should be mentioned that the organization for fighting aircraft fires on board ship is separate from the Damage Control organization. Its manpower is drawn from aircraft handling ratings of the Fleet Air Arm and the methods used are similar to those used ashore, except that mobile crash tenders are replaced by equipment operated from a flight deck fire main system.

COLD WEATHER AND ARCTICIZATION ARRANGEMENTS

Ships which operate in cold weather or under arctic conditions are as liable to fires as any other; perhaps more so, since there is much greater emphasis on heating. The problem is to ensure that water and appliances can be used in the temperatures likely to be experienced. Admiralty requirements are based on 25° F for cold weather and 10° F for arctic conditions, but it is possible that the latter figure will be superseded by a new N.A.T.O. standard.

The cold weather arrangements can be described briefly in general terms. Exposed pipes and flanges and spraying arrangements are lagged, as are the ring main and rising mains of hangar spray systems. Weather deck hydrants are fitted with an additional valve in the supply branch, well inside the main structure, so that exposed lengths of piping can be drained. Alternatively, these hydrants are fitted with steam coil heating and both pipe and steam coil well lagged. The latter method is used for flight deck fire hydrants. Where necessary, stowages for foam and water-type portable extinguishers are insulated and fitted with steam heating. This treatment is also applied for drums of foam compound at exposed hydrants. The arctic precautions include the foregoing, with the added requirement that fire pumps must take their suctions from the discharge side of the main condenser or drain cooler or similar discharge, so that warm water can be delivered to the fire main. Where the extreme fore and after ends of the fire main are exposed, ½-in. diameter leak-offs are fitted to ensure a continuous circulation of water. The leak-offs discharge either directly overboard or into a scupper with a warmed storm valve.

Air escapes and ventilation openings to gasoline compartments and compartments which contain other low flashpoint liquids are fitted with anti-flash gauzes, with steam-heated coils to keep them free from ice, the coils being shrouded from the direct influence of wind, snow or spray.

STANDARDIZATION

Because it is desirable for all three Services to use common equipment if this can be arranged, and since at present this is by no means the case, an Inter-Service Committee is considering the possibilities of standardization over the entire range of fire fighting equipment. The prospects of standardization between nations were investigated by N.A.T.O., but it became clear that little could be accomplished, or was necessary, other than an exchange of appliances, including portable pumps, in an emergency. To enable main equipment fitted with one type of hose coupling to be used in a ship of another navy fitted with a different coupling, it was agreed that a standard flange should be adopted. Ships in the Fleet are therefore to be equipped with adaptors consisting of their type of hose coupling at one end and the standard flange at the other. When equipment is loaned or received, the standard flange will be offered up to the corresponding flange on the adaptor similarly supplied to ships of foreign navies.

RESEARCH AND DEVELOPMENT

To a great extent, the fire fighting equipment used in the Royal Navy is of commercial design and most of the fire risks are of a conventional nature. Fundamental research by the Navy into fire fighting is scarcely necessary and can be done more economically by specialists. There are, however, a number of strictly Naval problems in which a certain amount of experimentation is necessary. In order to assess the merits of new items of fire fighting equipment, to carry out tests of materials suggested for use in the Navy and to experiment with new methods for dealing with particular hazards, a small establishment called the Admiralty Fire Test Ground is maintained at Haslar in Hampshire, staffed by one lieutenant and four civilians.

Equipment is tested functionally and the mechanical details examined from the point of view of ease of operation and maintenance. Materials are, where possible, given tests in which the fire severity accords approximately with the first five or ten minutes of the Standard Time/Temperature curve as defined in B.S.S.476/53. The test rig for this purpose usually consists of an oil fuel register burning kerosene under pressure which can be regulated.

Although the Test Ground is not a scientific establishment in the usual sense and has few facilities for precise experimentation, the work is carried out under realistic conditions with necessary attention to detail, and careful records are always taken. The following examples illustrate the scope of the work:—

Trials of Maintained Pressure Extinguishers.
Trials of the fire retardant properties of various materials for deck coverings and bulkheads.
Trials to investigate the danger of fuel spillage being ignited by rocket-assisted take-off aircraft.
Trials of various paints for coating asbestos lagging.
Trials of a new P.V.C. hose.

Apart from a wide variety of appliances, the Test Ground is equipped with a full scale mock-up of an

engine room of a *Dido* Class cruiser, and also of an M.T.B. engine room. The former was the scene of investigations which resulted in much of the Navy's present knowledge of fighting major fires with foam and steam.

At the moment, the Test Ground staff is engaged in a series of trials to evaluate the usefulness of dry chemical in naval fire fighting and to establish the best chemical and equipment for our purpose. Close touch is being maintained with the Fire Research Station at Boreham Wood, who are carrying out similar work, to ensure uniformity and avoid duplication.

Liaison is maintained with the fire research establishments of other services and departments, including the School of Aircraft Handlers, who deal with aircraft fires, and the fire fighting school at Portsmouth which, in view of its function as a training ground, is frequently called upon for user trials.

In addition to keeping in close touch with the research authorities at Boreham Wood, contact is also maintained with the R.A.F. Fire Fighting Establishment at Kenley and with the War Office and Ministry of Works, and the Admiralty is represented on various J.E.S.C. Sub-Committees associated with fire fighting problems.

Finally, it would not be proper to leave this subject without paying tribute to the members of the fire fighting trade who assist the Admiralty with trials and carry out tiresome modifications to their standard trade equipment at their request. It sometimes happens that the Admiralty are able to suggest modifications which can be incorporated in production models to the advantage of all.

CONCLUSION

The aim of this paper has been to show how the Royal Navy faces the problem of fighting and preventing fires in warships in peace and war.

Plans for the future depend on the lessons of the past and on changes in the make-up of the Fleet and on the effect of new hazards and new weapons. The Navy is becoming predominantly one of small ships and probably most future developments will be in appliances and media suitable for smaller vessels. Considerations of weight and space are becoming more and more important. Furthermore, the increasing complexity of a modern warship means that little training time can be spared for defensive tasks and maintenance jobs must be reduced to a minimum. Simplicity of maintenance and operation is therefore very important indeed.

There are considerable problems posed by the advent of thermo-nuclear weapons, but most of the subject is bedeviled by security considerations. Within a certain distance of one of these weapons, a ship and everything in her will be vaporized, to use the unpleasantly precise words of the physicist. Beyond that distance and in varying degrees, depending on the range, ships are likely to suffer all-embracing damage varying from complete disruption to mere scratches. Among ships so damaged, inevitably there will be some that will be set on fire and these fires are likely to break out simultaneously all over the ship. The work of fire fighting will be more difficult than ever before and much will depend on the way in which individual men and fire parties make immediate use of the equipment at their disposal—everybody will have to be a trained fire fighter.

In Virgil's "Aenead," it is said that when the Trojan warships were set on fire by the enemy the unfortunate victims called upon the gods, who came to their rescue by turning the ships into sea nymphs. For the ship unfortunate enough to get too close to a thermo-nuclear explosion, this is probably as good a solution as any.

The National Bureau of Standards has been studying flame characteristics for the purpose of developing reliable aircraft engine fire detection systems. Results indicate that reliability could be greatly increased by a system that would not respond unless the following characteristic properties of a flame were all present at the same time:

(1) Characteristic rate of increase of radiant flux,

(2) Sufficient level of radiant flux in the required spectral region,

(3) Characteristic frequency of flicker.

LYLE SPENCER

THE ROLE OF THE EXECUTIVE TODAY

ACKNOWLEDGEMENT

The following lecture was delivered before the Industrial College of the Armed Forces, on 14 September 1946 by Mr. Lyle Spencer, President, Science Research Associates. In 1940, Mr. Spencer was selected as one of the country's 10 outstanding young men by the U.S. Junior Chamber of Commerce. From 1938 to 1942, he was President of Science Research Associates. In 1945 he was discharged from the U. S. Army as a lieutenant colonel after having served for three years in the Information and Education Division as Executive Officer of the Research Branch and Chief of the Analysis and Planning Branch. He served in Africa, Italy, France, and Germany, and was awarded the Legion of Merit and the Bronze Star. Since 1945, he has been President of Science Research Associates. He is a member of the Board of Directors of a number of companies, former National Vice President of the Young President's Organization, and a member of the National Council of Consultants, Small Business Administration.

IT REQUIRES a good deal of temerity, to appear here today to talk on this topic when everyone present is a major executive himself. Only the thought that this meeting serves as a kickoff for our discussion later, which I hope will provide new ideas for all of us in this field, has persuaded me to attempt this talk.

One of the points about this topic that continues to surprise me is the amount of interest among executives in the question of executive development, possibly because underneath our confident exteriors all of us secretly feel that we are not doing nearly as well in our executive jobs as we should.

The executive is a topic that has concerned every thinker responsible for running a large organization almost since we have had social organizations. Not long ago I was reading some correspondence between John Adams and Thomas Jefferson written in 1813. Amidst this exchange of letters Adams complained that aristocrats monopolized the executive posts of that time, and that they got to be aristocrats by five routes—through beauty, wealth, birth, genius, and virtue. Only the last two of these, he said—genius and virtue—were really acceptable credentials for an executive position.

Mr. Jefferson went even further. Describing executives who obtained their posts through wealth, beauty, or birth as "artificial aristocrats," he proposed what amounted to a Federal scholarship system, to assure, as he said, a continuing flow of executive talent from every condition of life, completely prepared by education for defeating the competition of wealth and birth for positions of public trust. Now, more than 140 years later, attempts are still being made to get this sort of bill through Congress. The Ford Foundation recently put up twenty million dollars to get a similar idea rolling by creating the National Merit Scholarship Program.

Researchers in this field hold sharply divergent views about how important the role of executive development is and what can realistically be done in the way of training executives. One school holds that there just aren't very many good executives, except for those of us here in the room today; and that the low birthrate of the thirties, the lack of training opportunities during the depression, and the huge industrial expansion that has gone on unabated for the last fifteen years has caused the most severe executive shortage that we have ever known. These forecasters believe that the shortage will probably continue for at least the next ten years, and that it is more likely to put the brakes on our current business boom than even the current shortage of bank credit.

Another school of thought—and not an inconsiderable one—holds that executives are really just flattering their own egos with such talk; that the path to the top is paved with the broken dreams and ambitions of good men who have been shouldered aside; and that nearly every company has

more major league executive talent than the Yankees' farm chain.

I personally lean toward the former view, and become more convinced of it every time I try to find the right executive for an important post in my own company. Recently I was a member of a committee trying to find the right man to head a major Midwestern university. Like all personnel people, we started out by setting up our job criteria. We decided that there were at least four major credentials involved. First of all, we felt that the potential president had to be very bright, as befits a distinguished intellectual leader. Second, he needed to have the finest training and experience and to command the respect of his peers. Third, he had to understand youth and the problems of adolescence. Fourth, since the university had a large financial deficit, growing larger every day, he must be a dynamic, successful money raiser.

Well, we got out this list and sent it around to a number of people, including an Episcopalian bishop. He wrote back that he had the name of exactly the man we were looking for, but he didn't mention his name. So we wired back, and the return answer was: "His name is Paul and he was last seen in the vicinity of Tarsus about two thousand years ago."

Our group has done some research work in this area with a number of major companies on both executive selection and development, particularly with young executives. I would like to tell you today about some of the work we have been doing over the past four years with a group called the Young Presidents' Organization. It's a group of something over a thousand men and women who have become presidents of companies doing more than a million dollars worth of business annually before they themselves reached the age of forty. Most of these men are strongly expansion-minded, and nearly all of them face the kinds of problems that I suspect many of you do in your executive posts.

The consensus of this group is that the greatest bottleneck they face in the future growth of their businesses is lack of adequate talent in top management teams and in the echelon just below this level.

One of the other problems pointed up by these studies is that the inflow of executive potential is not what it might be. We find some corroborative evidence of this in some of the testing that we do for the Selective Service Administration, where we find that the students who are preparing to be business executives through taking business administration courses tend to be below average intellectually as compared to other students attending our colleges today. They are considerably below the caliber of the students who are preparing to be engineers, scientists, lawyers, or doctors.

Many of these young presidents have used phrases along this line: "If we can solve the personnel problems at the executive level, somehow most of our other problems will solve themselves."

Now, I am not going to talk to you today about recent research on factors relating to the better selection of executives, although this is a most interesting topic. If you are interested, perhaps in some of our discussion later we can get into that more. I would like to concentrate here on the results of four intensive field studies made on the relationship between the boss or the president of an enterprise and the members of his key executive team—how each thinks the other could improve his executive work, with some pungent comments of their wives, who, after all, are ex officio executives themselves. I'll try to use some illustrations that may be pertinent to the kinds of operations in which you are involved, as well as to private business.

In general, to outsiders the term "top management" often symbolizes a faceless, powerful, largely anonymous edifice within which decisions are made and orders issued in mysterious and impersonal ways. Even within most companies the top management group is often referred to in such distant terms as "they" or "topside" or "the front office." And to this "big brother" edifice is often attributed the characteristics of being all-seeing, ever-watchful, and sometimes slightly ominous.

These stereotypes are not true, obviously. In fact, there are few that are farther from the truth than these. The top management group in every company that we have worked with is always a small one, and it's always intensely human. Arch Patton, of McKinsey and Company has estimated that in any large business it usually comprises about one-twentieth of one per cent of the company's employees. In the YPO companies the average size is from three to five executives in addition to the president. This is almost exactly the same number of children that most presidents possess, and the analogy is more than a passing one.

Like families, the members of the top management team are usually held together by strong personal ties. They usually work together toward the same goals, that are often not very explicit; and the possibility of conflict is always present. They usually have great respect for the company president or "father" figure; but they sometimes exhibit the same type of petty rivalry that kids do, engaging in frequent not very serious squabbles among themselves, while exhibiting a calm and united exterior to the outside world.

Here is a composite picture of what the members of the top management team look like in most companies:

Typically the team includes an administrator. He serves as the president's alter ego and has the general responsibility, whether or not he has the actual title, of keeping the company's day-to-day operations running smoothly. On some days he looks suspiciously like an image of the president, particularly when the latter is out of town.

The other members of the team are usually vice presidents in charge of sales, production, and finance. Only occasionally are other executives,

such as those responsible for personnel, purchasing, and research, or the president's assistant, bona fide members of this team.

As might be expected, most presidents are currently and actively dissatisfied with the quality and the performance of their management team. This critical attitude is usually due less to the actual quality of their present executives than to the chronic, restless desire of most presidents to find more ways of improving and enlarging their own companies. Furthermore, effective presidents usually are acutely aware of how essential good executives are to their own personal success. It also seems probable that the chief executive who is most conscious of the defects in his present management team is usually the one who is already running the most successful company.

Here are some of the major reasons that presidents give for being dissatisfied with the operation of their present executive team: More than half of these thousand men we surveyed felt that their present executives would be unable to handle a substantial increase in the size or complexity of the company's business. These presidents felt that the necessary improvement should be made now rather than waiting for possible future business growth; and they had anxiety feelings because they weren't doing something more active about it. Frequently they felt stymied because of their ties of personal friendship or family relationship with various members of these key teams.

Indeed, many of these presidents felt that future company growth depended very largely on these essential changes being made. An equal number of presidents felt that their present managers possessed great growth potential, but that major changes and improvements were needed before they would be polished executives. A third of the presidents said that they had pointed out the changes that were needed, but that these improvements had not yet been accomplishd by their executives.

This is the point at which one of the major difficulties in running a top-level management team becomes most frequently apparent. It involves the president finding better ways of communicating more clearly with his executives about the real things that he wants done in terms that they fully understand. In general, most presidents already think that they communicate effectively with their managers. Over 85 per cent of them said that in individual meetings with their executives the problems they planned to discuss were satisfactorily settled. The key executives, when they were questioned, agreed that these discussions were satisfactory when they involved only day-to-day problems. Incidentally, more than a third of these problems involved personnel matters. They emphatically disagreed, however, when the discussion topic involved major company policy or key objectives of the company. The less important the topic, the better the communication. The most serious criticism that executives made of their president was the latter's inability to voice his deepest concerns about really important company or personal matters, although the president expected his executives to act as though they understood what these concerns were.

Said one executive: "I never know where I really stand on the big issues. When problems get big enough to be painful, the chief can't bring himself to talk about them." Said another: "He should clearly define company policy and organizational authority throughout the company." And a third said: "He should let me in on company problems, objectives, and goals and keep me generally informed about what he wants to have happen."

These points can probably be explained most clearly through examples. Please note in these examples both the communications problems involved, the difficulties that can arise when the president and one of his executives define differently the mission of the latter's job, as well as the unstated premises in their relationship that sometimes cause serious trouble.

Let's turn first to the post of the company's chief financial officer. Most financial officers regard their most crucial responsibility as being the maintenance and improvement of the company's accounting system. The president, on the other hand, is apt to take for granted the satisfactory maintenance of a good accounting system as being one of the things he pays an able financial officer to do. He singles out the financial officer for praise in this area only when there is some unusual element attached to it.

Far more than most accountants realize, the president relies heavily on the ability of his treasurer to keep him and the company out of money troubles and to issue early warnings when the first financial storm clouds appear on the horizon. As John Dewey once pointed out, "Facts do not bear their interpretation on their face." Accountants are more concerned about the figures themselves, the presidents about the implications that should be drawn from these figures. Presidents evaluate the success of accountants much more on their ability to draw correct inferences from figures than upon the compilation of the figures themselves. One president gave a rather typical example of this point: "Based on our treasurer's past forecasts, I worked out a line of credit and repayment with our bank which involved borrowing up to the hilt of our credit line. Within sixty days it was apparent that the forecast was dangerously optimistic. I felt like an idiot having to go back to the bank and explain that our estimates were all wrong. We were forced to retrench quickly, which produced serious losses."

Another point to note about financial officers, of which other members of the top management team are often more keenly aware than the president, is the treasurer's ability to move strategically against any other person in the company—the sales manager, the production manager, or the administrator.

Because of his role as scorekeepr, the financial officer provides the only really objective measure of how well the other executives are doing their jobs. Numerous top management frictions can arise when other executives either do not understand or do not agree with the assumptions that the financial officer makes in totting up the profitability of their operations.

The financial officer typically is in a relatively unique position in his company, since the sole judgment about his competence usually comes from within the company itself, mainly from the president. No one outside the company judges him in the same manner as customers judge the vice presidents for sales and production. No one within the company can judge of the success of his division as easily, as coldly, and as impartially as he can judge other divisions. Careful definition and agreement about accounting assumptions are therefore extremely important in minimizing intracompany frictions and hositilities.

Well, that's the first officer I'd like to mention. The second is the chief administrator. In most companies that is what would most frequently be called the executive officer in any military operation.

Virtually every executive team contains one man who is the chief day-to-day administrator of the company. On days when the president is feeling good about his administrative officer, the latter may be seen as his closest colleague, his personal confidant, his trusty right arm, the one indispensable man in the company. Because of his closeness to the front office, however, the administrator can quickly become a handy focus for aggression when things go wrong. Then he may be viewed as a visionless clod whose stupidity is dangerously hindering company progress.

Conversely, the administrator tends to think of his president as a likeable man, who serves a valuable public relations function and often dreams up good plans for the future, but who has a regrettable, immature tendency to go off halfcocked. In short, the chief administrator is typically the maintainer of the established order; and he will fight the president or anyone else who seeks to disrupt the company's daily routine. More than any other officer, the administrator serves as the balance wheel between the conflicting forces in a company in maintaining the status quo versus the desire for growth.

From examples gathered in our YPO survey, administrators seem to feel that they understand the rhythm of company operations and the maintenance of controls much better than their presidents. And when presidents discuss the shortcomings of their administrators, the topic of future planning and company growth are most likely to be mentioned as areas where the administrator is lacking.

Finally, the administrator is most often the man who has the delicate and unpleasant responsibility of speaking frankly to the president when criticisms of the chief executive are in order. Most executives wish that there could be a freer interchange of constructive criticism at the top level within their companies, but fear of arousing presidential displeasure is usually a powerful deterrent.

Here is how one administrator tried to handle his difficult assignment. "The president," he said, "of our company controls the stock and therefore has selected the board of directors. Our board now consists of officers of the company, including myself, and a number of inactive relatives. We badly need a broader board of directors, including executives of other companies, to aid us in our growth and to help our executives in pointing out company weaknesses to our president. He listens, but he has done nothing about it; and I strongly suspect that he is afraid of having his own control reduced."

Because of lack of time here, I am going to skip the sales vice president, who is a really key man in most business organizations. Also I assume that the area of sales is less related to the type of executive situations that most of you are dealing with. I would like, therefore, to take as the next area the production manager. I don't know whether he would be called the supply officer, or in some cases the G-3, or exactly what his post would be in a military organization; but he is the man who in most companies must maintain the flow of the output of goods going out the back door on which billings can be made.

Production managers tend to think of their mission as that of maintaining a steady or increasing flow of goods at a minimum cost. Possibly more than any other man in the company, they must exercise continuing care to see that their functions interlock and mesh properly with other activities and plans of the company. The production executive is more likely to rise from the ranks within the company than any other major executive. Crucial incidents that company presidents recounted about their production managers deal most often with their getting the goods out on time in the face of seemingly insurmountable odds. They dealt frequently also with developing facilities or mustering task forces to meet heavy production demands brought on by changing markets or by fast-moving sales forces.

Just as one example, a president mentioned the following example: "January floods in California," he said, "wiped out our crop for processing. He secured," meaning the production manager, "raw produce throughout the state to keep our three plants in operation. Our competition was unable to secure raw products. We kept in operation and more than tripled our profit during the year."

On the other side, another company president mentioned the fact that when copper prices were rising during the recent squeeze a year or so ago, the production manager thought that the prices of copper were too high. He did not lay in the normal supplies that he should have. So during the peak of the season the company was shut down for a period of more than six weeks just at the time when they

should have been going at top speed. In other words, he had not foreseen the problems that were going to come up the day after tomorrow.

One other topic I would like to mention here is the survey of the wives of presidents that we made this last year. The most serious problem that many busy business executives typically have to deal with is their wives' lack of understanding of their jobs. Most executives' homes have more than their share of family frictions, although this is not generally noted on the outside. The most frequent point about which frictions are likely to occur is disagreement between the husband and the wife about how the president spends his time.

According to this survey, the average company president works about fifty-one hours a week in the office. Many of the wives feel that besides these fifty-one hours a week, he carries his business problems home with him; that whatever else he may seem to be engaged in, it's the problems of business that are constantly uppermost in his mind—at the dinner table, out at the country club, around the TV set, or even in the boudoir.

While this point is rarely verbalized, many wives unquestionably equate their husbands' preoccupation with business problems with their love for them. They jealously suspect that the company rates higher in his affections than they do. Wives who have worked before marriage feel less strongly about this matter than women without previous business experience. Most husbands, according to their wives, pooh pooh this point when it arises and seem generally incapable of understanding why their mates should cherish such ridiculously feminine notions.

Lack of mutual understanding in this area and the tensions produced by it flash out in many unexpected ways. I am not going to have time to give many examples here, but I did want to mention just a couple of them, because I have been astounded by the frequency with which this sort of thing has seemed to occur among the executive groups that we have analyzed.

Business expansion is the heart beat of most industrial enterprises, at least in the view of the company presidents. The prestige and status of most presidents are intimately related not only to their ability to make their company grow in dollar volume, but also to whether their companies are able to keep pace with the expansion rates of their competitors. This is a point we noticed again and again —that even more than the actual making of money is the president's consuming, driving desire to beat his competition.

Curiously, many wives are at least passively and not always silently opposed to such expansion. Said one wife: "We already have more than I ever thought we would in our whole lives five years ago. when he became president. Now he wants to open a West Coast branch and I'll never get to see him any more." Commented another: "My husband is thinking of buying out a competitor, and I just can't see it. We'll be risking everything we have and his work will be doubled, and what good will it all do? We already have more than we know what to do with."

Several score other cases provide eloquent testimony about the fears of many wives regarding continuing business expansion. Little as she sees of her husband now, she darkly suspects that she will see even less of him as the business grows. This can only mean that the business wife is gaining ground in his affection, while she, burdened with the home and kids, is losing out. It's a wise executive who can get his wife to understand and agree with the time requirements and the business commitments of the American industrial world.

These examples touch only a few high spots from our several YPO surveys, and I hope that they are relevant to our discussion here today.

I was impressed with the relationship of some of these things to the movie entitled "Pattern," which we all saw today, because this business of industrial executive crackup is not just a figment of our imagination or the sort of thing we see in movies. It happens all the time. This matter of maintaining a reasonably low anxiety level among major executives is certainly a problem that we don't know anywhere near enough about and one that deserves a good deal more study than it has had so far.

One of the other things that we know about many of these executives is that the most successful ones have compulsive drives for success that force them to keep going ahead; and these drives often produce human relations problems that the executives are not always able to deal with.

Another sort of thing that happens is a fierce desire for self-improvement that we noticed among so many of these executives. This is frequently more true of the younger executive than it is of the older ones.

To get some of the background data along this line that we have run across, let me state that the average executive who is now under forty has about four and a half years more of formal education than does the major executive who is over fifty. Yet two-thirds of the younger ones are actively engaged in some sort of activity that involves self-improvement. Mainly, I think, because most of these men came up to major executives positions after the depression, they feel that they have not had the wide executive experience that older men have, and they feel a defensiveness about their lack of preparation.

The two consuming areas where this desire for self-improvement occur most frequently are: anything that has to do with more effective sales programming and anything that has to do with more effective financial control. Nearly all of these YPO companies suffer from a lack of adequate working capital, and anything that their presidents can learn

about how to make their working capital stretch farther is of great interest to them.

In terms of their personal problems, the topic that they are most concerned about is their inability to delegate work adequately. Most of these men, as I said before—and I suspect it's true of most of you also—got where they were by gaining a reputation for being "doers;" they got things done while other people were still talking. When they got to the post of president, if they had not wrestled with the problem of delegation before, they had it in a serious way then—that no matter how able they were, no matter how hard they worked, no matter how many hours they put in, they physically could no longer do the entire job themselves. So this meant making a major shift in their orientation from doing things themselves to getting things done through other people, which requires qualities of leadership and human relations which they had not been paying particular attention to before that time.

If I may try to summarize briefly the overall conclusions that we might draw from these studies—and these may be topics that would be worth our discussing farther today—I'd like to turn again to the analogy between the role of a top management executive and the head of a family.

The president in most companies, certainly where the president is an effective manager, definitely plays the role of the father in the psychiatric sense; and the rest of the team represent either his sons or elder relatives. Motivating executives effectively can often be as complicated and exasperating a task to a president as motivating his children; and all of us know how difficult that is.

Most of us tend with our executives to overemphasize the motivating rewards of money and financial bonuses and to overlook other important but less tangible rewards. While the desire to earn more money is unquestionably an important and a strong motivating force to all executives, or nearly all of them, even more important in their eyes are the respect and affection of their presidents and colleagues in the top management team. Also important to them are the feelings of personal satisfaction that they derive from feeling that they have done a job well themselves.

It is important to remember that the members of a good executive team have usually been selected, or have been so trained, that they largely monitor their own conduct. This point is not typically true farther down in the management echelon. In large measure, effective executives administer their own rewards and penalties; and our main problem in managing them is to plan, coordinate, and guide their work.

An effective top executive is usually his own most critical judge and jury. Not only is he acutely conscious of the business incidents which do him credit or of which he is ashamed, but by and large the punishment or reward for the incident is meted out by the executive to himself. In fact, for almost a quarter of the critical incidents that we collected in these surveys which the key executives described about themselves, they did not feel that the president even knew when they had made a major mistake.

Most executives require the satisfying experience of accomplishment. Most of them have a sneaking suspicion that they really are not quite good enough for their present job, and they require the constant reassurance that they derive through continuing accomplishment. This drive is apparently an essential ingredient of continuing business success.

Finally, most key executives feel that they could do their jobs better if their immediate superior, usually the president of the company, would explain company policy to them in more detail. By the way, only about 40 per cent of these presidents had regular, systematic review sessions with their executives to tell them how they stood and what the plans for the company were in the immediate period just ahead. Most presidents think they do a much better job in this area than they actually do.

The second thing that the key executives wish is that their presidents would interfere less with the operating details of their major staff members. This is not a problem that is unknown in the military service either.

Finally, the key executives would like to feel that they knew better where they stood in the eyes of their presidents; that they had regular periods when their work could be reviewed; and that their presidents would be franker and more candid with them in outlining both their strong and their weak points.

Thank you very much.

JOHN FLODIN

DEFLECTION OF BEAMS OF VARYING MOMENTS OF INERTIA

THE AUTHOR

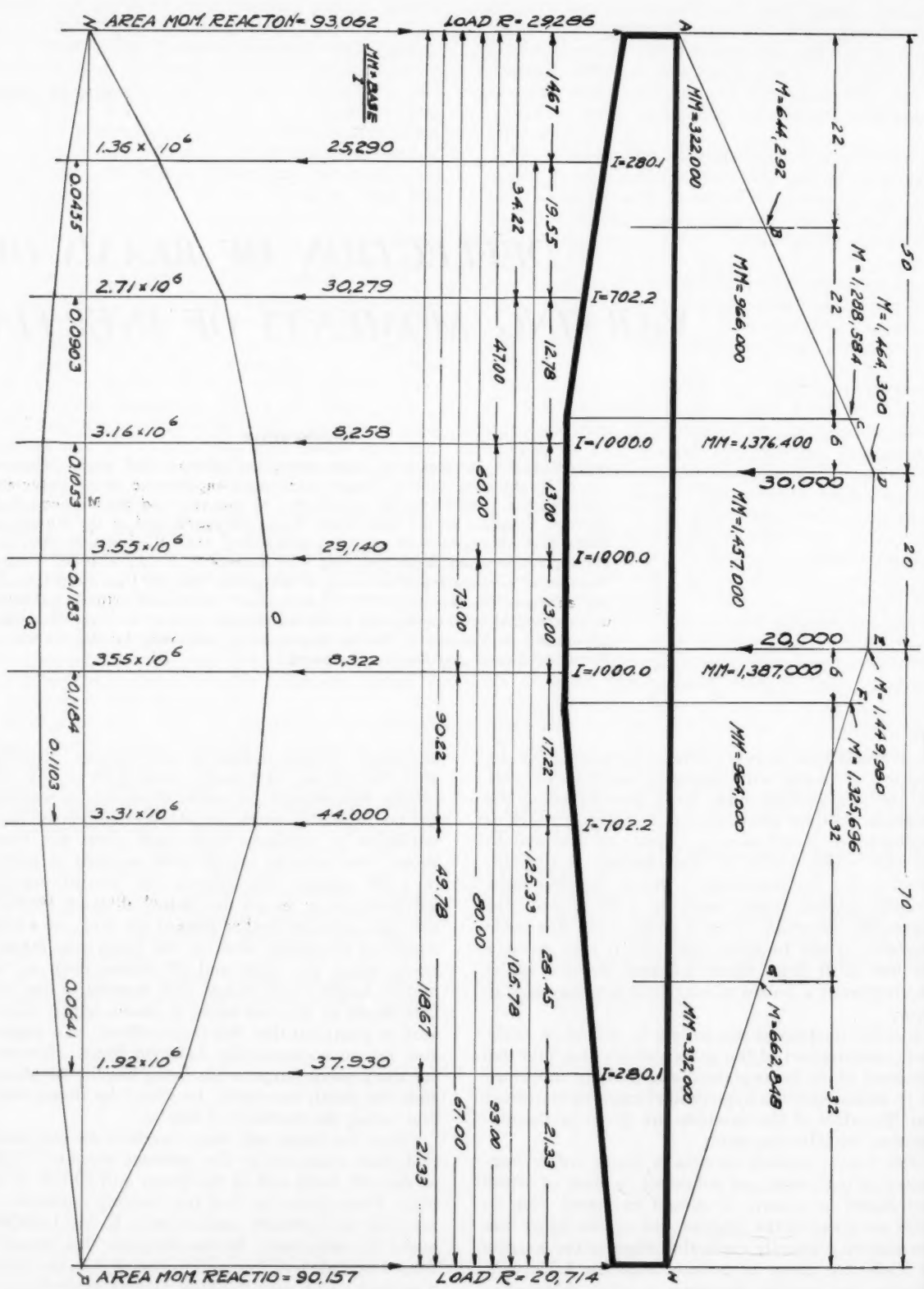
earned his B.S. in mechanical engineering and later his M.E. degree, University of Washington, Seattle. Taught mechanical engineering at the University of Minnesota, 1923–31, during which time he was awarded the M.S. and M.A. degrees. Engineer at the New York Naval Shipyard, and at the Bureau of Ships, specializing in deck auxiliary machinery, 1932–41. Assistant chief engineer, Lidgerwood Manufacturing Co., Elizabeth, N. J., 1941–46. Taught mechanical engineering, University of Maryland, 1946–48. Currently consulting engineer, Washington, D.C. Contribution: numerous articles published in commercial engineering and other magazines; chapter on Deck Auxiliary Machinery in Volume 2, Marine Engineering, published by the Society of Naval Architects and Marine Engineers.

TEXTBOOKS GIVE several methods for finding the deflections of beams with changing moments of inertia, the one perhaps most often favored being the graphical method based on moment areas, which is explained in detail, among others, by Norman in his MACHINE DESIGN. The method is straightforward and not too complex, but it requires painstaking drawing board work at a large scale for reasonable accuracy as it involves such fine-angle diagrams as the funicular polygon. It also involves the use of at least three different decimal scales which often is a source of confusion and may lead to error.

It is the purpose of this article to outline an arithmetic counterpart of the graphical method, and this can most easily be explained and perhaps most easily be understood if a hypothetical example is worked out. The data of the example are given in the diagram on the following page.

The heavy outline denotes a beam freely supported at both ends and subjected to loads of 30,000 and 20,000 as shown. It should be noted that no units are given in the diagram, the reason being that the method is equally applicable whether the weights or loads are given in pounds, tons, or kilograms, whether the lengths, distances or other dimensions are given in feet, inches, or centimeters, provided only that logical uniformity is adhered to and that proper adjustments are made. However, in working out the present example, pounds and inches and their multiples or products were used. Thus the beam shown was selected for an even moment of inertia of 1,000 inches^4 throughout the central portion, which equals in length the 20-inch distance between the loads plus six inches toward the ends, or a total length of 32 inches. That is, the beam was made a single plate 1½ thick and 20 inches deep at the middle length of 32 inches, and tapered to one half that depth at the two ends. It seems hardly necessary to point out that this is not offered as a suggestion for an economically designed beam. However, for the present purpose this beam has the advantage that the depth can easily be found by direct ratio, and hence the moment of inertia.

Given the loads and their locations we can easily find their reactions in the ordinary manner, 29,286 at the left hand end of the beam and 20,714 at the right. From these we find the bending moments; at point D, M=1,464,300, and at point E, M=1,449,980, again by arithmetic. In the diagram this graph is drawn to scale and it is well to sketch it in as it gives a picture which aids thinking, though scale drawing


AREA MOM. REACTON = 93,062
LOAD R = 29286
MM/I BASE
1.36 x 10^6
25,290
+0.0455
2.71 x 10^6
30,279
+0.0903
3.16 x 10^6
8,258
-0.1053
3.55 x 10^6
29,140
-0.1183
3.55 x 10^6
8,322
-0.1184
0.1103
3.31 x 10^6
44.000
0.0641
1.92 x 10^6
37.930
AREA MOM. REACTIO = 90,157
LOAD R = 20,714
I=280.1
I=702.2
I=1000.0
I=1000.0
I=1000.0
I=702.2
I=280.1
1467
19.55
34.22
12.78
47.00
13.00
60.00
13.00
73.00
17.22
90.22
25.39
105.78
28.45
118.67
21.33
49.78
60.00
67.00
93.00
21.33
MM=322,000
MM=966,000
MM=1,376,400
MM=1,457,000
MM=1,387,000
MM=964,000
MM=332,000
M=644,292
M=1,288,584
M=1,464,300
M=1,449,980
M=1,325,696
M=662,848
22
22
6
6
6
32
32
50
20
70
30,000
20,000
A
B
C
D
E
F
G
H

is not necessary. It should be understood that as the diagram was prepared for publication it was made something of a picture, but the work can be done on a scratch pad when seated in a comfortable chair. Also, the numerical results given were worked out by longhand figuring while for practical purposes slide rule calculations are sufficiently accurate.

The peaks of the bending moment graph come at points D and E, as shown, but the full depth of the beam continues to point C at the left and to point F at right, giving varying bending moments over the two lengths CD and EF while the moment of inertia over those lengths is constant. The bending moment areas below CD and EF must therefore be treated separately, as must also be done with the area below graph line DE. Thus are left areas below graph lines AC at left and FH at right, both of which are too large to be treated as single units. It should be evident that, in work of this kind, if any lengths were divided into infinitesimal units we should obtain the accuracy of integration. This, however, is an unattainable goal when an arithmetic solutions is sought as it is with a graphical solution. But we can, without too much complication of the work, divide both the above areas into halves horizontally, that is, we may divide the base of the triangle under AE into two lengths of 22 each, and the base of the triangle under FH at right into two equal lengths of 32 each. We have now to deal with areas under graph lines AB and BC at left, and under FG and GH at right, in addition to the three areas at the central portion of the beam.

We have thus seven parts of the bending moment graphs, giving the seven areas shown, each with its average or mean bending moment as indicated by the symbols MM within the respective areas. For the triangular areas at the ends of the beam this average or MM value is simply one half of the moments at the inner ends. For the other areas it is one half the sum of the bending moments at the ends of the respective areas, as for example for the second area from the left, it is $644,292 + 1,288,584 \div 2 = 966,000$, insignificant digits being omitted. These values of the mean moments are stated within the respective areas. The mean moments are taken as acting at the centrodes or centers of gravity of the various areas.

Finding the locations of the centrodes of such areas as we have to deal with in a straight-line bending moment graph, or in cases approaching straight-line graphs, deserves a few words of explanation. Considering again the second area from the left, we see that the ordinates or the bending moments at the ends of that area are in a definite ratio, in this case one to two. We can now divide the area into two unequal parts by a horizontal line drawn from the top of the ordinate M=644,292, giving a triangle above and a rectangle below the horizontal line. Both these have the same base of 22 and the same height, which is M=644,292. For the triangle, the centrode from the left hand end is at two-thirds of the base, or at two-thirds of 22= 14.67, and we may give the area a weight of one. For the rectangle, the centrode from the left hand end is at one-half the base, or 11, and we may give the area a weight of two, thus maintaining the one to two ratio. Multiplying and adding we have $14.67 \times 1 + 11 \times 2 = 36.67$. Dividing by the sum of the assigned weights, that is by 3, gives 12.22 as the distance of the centrode of the combined area from the left hand end, or from the perpendicular through point B. Like reasoning gives the locations of the other centrodes, except that here the bending moment graph between the loads is assumed to be horizontal so that the centrode falls at 10 units from either end, or is located at the midspan. By simple summation we may now find the various locations of the centrodes, 14.67, 19.55, 12.78, etc., which have been written directly below the beam contour in the diagram, where the vertical lines through the centrodes are carried all the way down as they will be of future use.

The next step is to find the moments of inertia of the beam at the various bending moment area centrodes. This work has been simplified by making the beam a single plate evenly tapered toward the ends, giving the depth of the beam by simple ratio. The required moments of inertia are stated within the beam: I=280.1, I=702.2, and I=1,000 for the central portion of the beam.

We have now to deal with a number of complex quantities each of which is the product of the base of any moment area multiplied by the mean moment (MM) of that area and divided by the moment of inertia of the beam at the centrode of the same area. Thus we have, for the triangular area at the extreme left, $322,000 \times 22 \div 280.1 = 25,290$, and for the next area toward the right, $966,000 \times 22 \div 702.2 = 30,279$, and so on. These and other similar results have been written along the vertical lines though the centrodes in the diagram and are labeled at the left $\frac{MM \times BASE}{I}$. Dividing these results by the moment of inertia is necessary since the deflection is inversely proportional to that characteristic of the beam.

The values for $MM \times BASE \div I$ are now treated exactly as the weights or loads on a beam for which we have already found the locations, that is, the locations of the centrodes of the respective areas. These new loads give the "AREA MOM. REACTIONS of 93,062 at the left and 90,157 at the right, as shown on the diagram. Using these reactions and the quotients written vertically along the centrode lines as weight data we can find the imaginary bending moment at any point along the beam. Thus we get the quantities 1.36×10^6, 2.71×10^6, etc. Carrying out the bending moment analogy, the new bending moment graph NOP is shown on the diagram to scale but this is not necessary in ordinary calculations.

The final step is to divide the bending moments of the area-moments just found by the modulus of elasticity, which here has been taken at 30,000,000 for simplicity. The resulting quotients are the desired deflections and they have been shown by the graph NQP in the diagram. If a picture is desired, these deflections can be drawn to scale and the graph can be faired in, but ordinarily this is not necessary. If the purpose of the work is to find the natural period of vibration of the beam, only the deflections at the loads are desired and more than half of the calculations in this last step can be omitted.

It may be noted that two of the deflections, 0.1183 and 0.1184, differ slightly from one another while the vertically written figures directly above them are exactly equal. This apparent discrepancy is due to the dropping of decimals in writing down the vertical figures for the pseudo bending moments.

A mast or a kingpost may be regarded as a vertical beam, using the horizontal or transverse component of shrouds or topping lift as one reaction and the horizontal component at the heel as the other transverse reaction. The load is then the force against deck or platform which falls between the above reactions, and in the case of a kingpost that load may be a bearing. Such a problem is likely to be simpler than the example here developed as a mast or kingpost ordinarily has to withstand only one significant transverse force between the reactions at the ends. In handling such a problem, the resulting deflections should be faired and a straight line should be drawn through the heel reaction and the load at deck of platform. The deflection graph will then depart from the straight line at the upper end of the mast or kingpost and that deflection can be scaled off the graph at right angles to the straight line just drawn.

Progress in the production of energy in quantities for power application is indicated in test results of a thermo-electric liquid metal pump. Such a pump, with a heat exchanger, has circulated liquid sodium at rates up to 19 gpm with no electric power input. The energy is derived solely from thermo-electric currents, produced by temperature differences across a chromel and constantan strip positioned between the hot and cold tubes within the heat exchanger. Resulting electromagnetic flux provided the motive force on the liquid metal.

HEAT TREATMENT OF CARBON AND LOW-ALLOY PRESSURE-VESSEL STEELS

ACKNOWLEDGEMENT

This report, sponsored by the Materials Division of the Pressure Vessel Research Committee, describes the requirements prescribed by the A.S.M.E. Boiler and Pressure Vessel Code for the various steels commonly usd for pressure vessels; and summarizes general heat-treating practices employed by most pressure vessel fabricators and plate manufacturers. Authored by Mr. O. R. Carpenter and Mr. C. Floyd, the report appeared in the Welding Research Supplement of the February, 1957, edition of "The Welding Journal." Mr. Carpenter and Mr. Floyd are Executive Assistant and Chief Metallurgical Engineer, respectively, of the Barberton Works, Babcock and Wilcox Company.

SECTION 1: INTRODUCTION

THIS REPORT has been prepared to summarize the present knowledge of heat treatment of pressure-vessel steels and to point out gaps in the present knowledge of this subject which require further investigation and careful study.

In the subsequent sections the pressure-vessel steels are divided into groups primarily based on their chemical compositions. For each group, a detailed discussion is then given of the heat treatment prior to cold or hot forming operations, as well as any intermediate heat treatments that may be required during fabrication of the pressure vessels; and, finally, a recommendation is made for the final treatment of the pressure vessels in that group.

The authors wish to point out that with the exception of carbon-steel pressure vessels, the published data on this subject is scant; therefore, we are presenting information that is based primarily on the general heat-treating practices employed by most fabricators of pressure vessels, as well as those practices used by the plate manufacturers.

The authors wish to emphasize that the details of the various fabrication operations are common practices employed by several fabricators, but are not presented with the intent of standardizing shop practices—merely as general information.

The requirements of the ASME Boiler and Pressure Vessel Code (1956 Edition) are given below:

Section I, "Rules for Construction of Power Boilers," of the ASME Boiler and Pressure Vessel Code states the basic requirements for stress relieving of power boilers in Paragraph P-108, which are as follows:

> Except as specifically provided otherwise in the Code, all fusion-welded pressure parts of power boilers shall be stress relieved. It shall be done by heating uniformly to at least 1100° F, and up to 1200° F or higher, if this can be done without distortion. Different temperatures may be used to obtain proper stress relieving when required by the characteristics of the material.

Section VIII, "Rules for Construction of Unfired Pressure Vessels," of the ASME Boiler and Pressure Vessel Code, gives the following detailed information on thermal stress relief in Paragraph UCS-56 of Subsection C for carbon and low-alloy steels:

> Vessels or parts of vessels shall be thermally stress relieved by one of the procedures given in Paragraph UW-40 when the plate thickness, including corrosion allowance, at any main welded joint in the vessel shell or head exceeds any of the following values, or when required by Paragraph U-1(e), UCS-67 or UW-2:
>
> (1) Zero thickness for steels conforming to Specifications SA-301 Grade B, SA-302, SA-217 Grades WC4 and WC5, SA-357, SA-387 Grades B, C, D and E, and for chromium-molybdenum steel having a chromium content greater than 0.70%;
>
> (2) 0.58 in, for steels conforming to Specifications SA-202, SA-203, SA-204, SA-225, SA-299, SA-301 Grade A, SA-387 Grade A, and for any steel having a specified molybdenum content of 0.50% nominal (permissible range 0.40 to 0.65%) with a chromium content not greater than 0.70%;
>
> (3) 1.00 in. for steels conforming to Specifications SA-212, SA-105 Grade II, SA-181 Grade II, SA-266 Grade II, SA-95 and SA-216 Grade WCB;
>
> (4) 1.25 in. for all other steels that may be used in welded construction;

(5) A thickness greater than $(D + 50$ in.$)/120$ where D = inside diameter, in., used in determining the required thickness of the vessel or vessel part, or 20 in., whichever is greater.

. . . A minimum temperature of 1100° F* shall be maintained for a period of 1 hr. per inch of metal thickness (maximum metal thickness of the shell or head plate).

In order to prevent any confusion in the various types of heat treatments discussed in this report, the following basic definitions† are given.

Anneal: Slow cool from above the upper critical temperature or A_3 temperature. The annealing temperature for carbon and low-alloy steels is in the range of 1550 to 1675° F, depending on the type of steel. The steel is slowly cooled to 1200° F for carbon steels and possibly as low as 1000° F for some of the low-alloy steels. The rate of cooling below the above temperatures depends on the type, geometry and size of the material being heat treated. This heat treatment is generally called a full anneal.

Normalize: Cool in still air from above the upper critical temperature or A_3 temperature. If a furnace load is removed from the furnace on a car, it is mandatory that the furnace load be removed from the car as quickly as possible and the plates or parts cooled in air. The normalizing temperature for carbon and low-alloy steels is in the range of 1600 to 1800° F, depending on the type of steel.

Quench: Rapid cool in liquid from above the upper critical temperature or A_3 temperature.

Stress Relief, Temper or Postheat Treatment: Heat to a temperature not exceeding the lower critical temperature or A_1 temperature. Stress relieving or tempering heat treatments generally range from 1100 to 1350° F, depending on the type of steel, except as noted for Section VIII, "Rules for Construction of Unfired Pressure Vessels." The rate of cooling from the stress relieving temperature depends on the type, geometry and size of material being heat treated. This heat treatment is sometimes called a process anneal, subcritical anneal or postheat treatment after welding.

Plates may be purchased from the mill in the hot-rolled, annealed, normalized, normalized-and-tempered or quenched and-tempered condition, depending on the type of steel and the particular facilities available to the fabricator to perform various types of hot or cold forming operations, heat treating equipment and other similar factors.

The limits for cold forming depends on the thickness of the plate and the radius to which the plate is to be bent. The radius of bending is generally based on a maximum per cent strain on the outer fibers of the plate or an outer fiber stretch of 3 to 4½ per cent, depending on the material being cold formed, without requiring an intermediate stress-relieving heat treatment.

Strain on outer fiber of plate or outer fiber stretch may be calculated as follows:

$$S = \frac{R_1 R_2 - \frac{1}{2} R_1 T}{R_1 R_2 - \frac{1}{2} R_2 T} - 1$$

or

$$\%S = S \times 100\%$$

where

S = strain.
R_1 = final radius.
R_2 = original radius (for flat plate use a value of 1000 in.).
T = thickness of plate.

Other important factors that control the maximum per cent strain on the outer fibers are plate width, direction of bending or whether the plate is formed at room temperature or heated to some temperature below 1150° F (in the case of some of the low-alloy steels) just prior to cold forming. Cold forming at room temperature in the winter may be quite different than performing the same operation in the summer.

Although an outer fiber stretch of 3 to 4½ per cent may seem low, it should be recognized that this figure represents an average strain along a smooth surface, whereas the usual plate surface invariably contains some abrupt depressions where the actual local strain can considerably exceed 3 to 4½ per cent. Failure to allow for excessive local straining during the cold forming operation may cause local ruptures to occur in the plate. Under some circumstances local ruptures could act as a triggering mechanism to produce cracks and possible failure of the plate during forming.

If the cold forming operation requires more than 3 to 4½ per cent outer fiber stretch, depending on the material being cold formed, it is a general practice to cold form in two or more stages with the application of an intermediate stress-relief heat treatment when the first stage of cold-forming has approached the 3 to 4½ per cent outer fiber stretch.

In many cases the ability of the fabricator to cold or hot form plates may depend on the equipment and other facilities available for such operations.

* When it is impracticable to stress relieve at a temperature of 1100° F, it is permissible to carry out the stress relieving operation at lower temperatures for longer periods of time in accordance with the following tabulation:

Metal temperature, ° F	Holding time, hr. per in. of thickness
1100	1
1050	2
1000	3
950	5
900	10

For intermediate temperatures, the holding time shall be determined by straight-line interpolation.

† See also standard definitions of metallurgical terms, ASM Metals Handbook.

SECTION 2: HEAT TREATMENT OF CARBON-STEEL PRESSURE VESSELS

The following ASME Specifications cover the flange and firebox quality plates for carbon-steel pressure vessels:

SA-201. Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels.

SA-212. High-Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels.

SA-30. Boiler and Firebox Steel for Locomotives.

SA-285. Low- and Intermediate-Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities.

SA-30 and SA-285 specifications, representing low and intermediate tensile strength plates, make no references to heat treatment other than the mention of stress relief (1100 to 1200° F) of test specimens when so specified on the purchase order with the mill. SA-30 and SA-285 plates are limited to a maximum thickness of 2 in. and are generally tested at the mill in the hot-rolled condition.

SA-201 and SA-212 plates contain the same requirements as SA-30 and SA-285 for plates 2 in. and under in thickness, i.e., the material is tested in the hot-rolled condition unless the purchase order with the mill specifies that the test specimens be stress relieved at a temperature of 1100 to 1200° F.

SA-201 and SA-212 specifications contain a special section entitled "Heat Treatment," which is as follows:

Plates over 2 in. in thickness shall be treated to produce grain refinement either by normalizing or heating uniformly for hot forming. If the required treatment is to be obtained in conjunction with the hot-forming operation, the temperature to which the plates are heated for hot forming shall be equivalent to and shall not significantly exceed the normalizing temperature.

Cold Forming of Carbon-Steel Plates and Heads

The maximum thickness permissible for cold forming is dependent on the radius to which the plate or head is to be bent. This radius is generally based on producing a maximum outer fiber stretch of 4 to 4½ per cent in the plate or head without requiring an intermediate stress-relieving heat treatment. If the cold forming operation requires more than 4 to 4½ per cent outer fiber stretch, it is a general practice to give an intermediate stress-relieving heat treatment after each increment of outer fiber stretch of 4 to 4½ per cent in the series of cold forming operations. Experience indicates that plates less than 1¾ in. thick can be cold formed without normalizing prior to the cold-forming operation if proper equipment is available. The hot finishing temperature at the mill for plates less than 1¾ in. thick is usually sufficiently low to give a fine-grained structure which is equivalent to a normalizing heat treatment.

When plates are within the thickness range of 1¾ to 2½ in., they can sometimes be cold formed if it is a fine-grained material and the equipment is suitable for this work. The grain size may be checked by microexamination of a sample removed from the plate. If not fine grained, the plate may be normalized before cold forming. Normalizing is generally performed at 1600 to 1650° F with a holding time of 1 hr. per inch of thickness in this temperature range followed by air cooling.

The above information on plates in the thickness range of 1¾ to 2½ in. generally applies to the cold forming of plates exceeding 2½ in. in thickness where circumstances require this type of forming operation.

Heads are usually hot pressed rather than cold formed. The exceptions to this statement will be relatively thin heads of suitable diameter such that no tearing or wrinkling can occur in the head during the cold-forming or cold-pressing operation.

Hot Forming of Carbon-Steel Plates and Heads

Procedures for heating plates and heads should be so established that a plastic plate is obtained for the hot forming or pressing operation without evidence of oxidation in the form of severe decarburization and/or the formation of a network of oxide penetrations or surface checking known as "chicken-wire" cracking, which can cause permanent damage to the plate surfaces.

The following hot-forming temperatures have been successfully used:

Plate thickness, in.	Hot forming temperature, ° F
Up to 3 in.	1650
Over 3 in., up to 4½ in.	1750
Over 4½ in.	1850

The above temperatures are predicated on the use of a holding time of sufficient length at a temperature of 1500 to 1650° F to insure a suitably plastic plate for hot forming or pressing.

Some fabricators may prefer a higher hot-forming temperature range, possibly as high as 1800 to 2000° F. This procedure requires a rapid heating rate to this temperature range and a holding time of very short duration to avoid the possibility of decarburization or "chicken-wire" cracking at these high hot forming temperatures.

Where the lower hot-forming temperatures are used, the plates may remain fine grained and not require a normalizing heat treatment. This may be verified by a microexamination of a sample from the hot-formed plate. With regard to the higher hot-forming temperatures, experience indicates that plates so heated are coarse grained, in most cases, after hot forming, and generally require a normalizing heat treatment after this operation. The normalizing heat treatment used by most fabricators is heating to 1600 to 1650° F, holding in this temperature range for 1 hr. per inch of thickness, followed by air cooling.

Hot formed plates are cold formed or "cold sized" to obtain the required tolerance on circularity. No

heat treatment is required after this cold-sizing operation since the outer fiber stretch is much less than 4 to 4½ per cent; in fact, in most cases the outer fiber stretch is less than 1 per cent.

Heavy head plates may be hot pressed in the temperature range of 2100 to 2150° F. This heating operation involves rapid heating to this temperature range with a very short holding time to avoid decarburization and/or "chicken-wire" cracking. This applies particularly to head plates over 2 in. thick. Heads that are less than 2 in. thick may be hot pressed in the temperature range of 1800 to 2000° F. It is a general practice to normalize all heads that are 2 in. or more in thickness. This normalizing heat treatment is identical to that outlined in the preceding paragraph for plates.

Intermediate Heat Treatments During Fabrication of Carbon-Steel Pressure Vessels

Any intermediate heat treatments required during the fabrication of carbon-steel pressure vessels, after hot- and/or cold-forming operations are completed, are generally performed in the temperature range of 1100 to 1200° F. The intermediate heat treatments required are determined by the thickness of the section, the carbon content of the plate and similar factors.

Final Heat Treatment of Carbon-Steel Pressure Vessels

It is common practice to apply a final heat treatment, after fabrication is completed, in accordance with the requirements of Section I or Section VIII of the ASME Boiler and Pressure Vessel Code. If a final heat treatment is required, the vessel may be heated slowly to a temperature range of 1100 to 1200° F, held 1 hr. per inch of thickness, and cooled slowly in a still atmosphere to a temperature not exceeding 600° F.

SECTION 3: HEAT TREATMENT OF CARBON-MOLYBDENUM-STEEL PRESSURE VESSELS —ASME SA-204

SA-204 contains specifications for flange and firebox quality plates for carbon-molybdenum-steel pressure vessels. The general information outlined in Section 2 of this report on the heat-treatment procedures after cold or hot forming of plates and heads applies equally well to carbon-molybdenum pressure vessels except that some fabricators may require a stress-relief heat treatment after normalizing for Grade C (75,000 psi tensile strength) plates or heads. The same general comments on intermediate heat treatments for carbon steels in Section 2 are applicable to carbon-molybdenum steels.

Some fabricators use a slightly higher final heat-treating temperature range for carbon-molybdenum than for carbon-steel pressure vessels. If the ASME Boiler and Pressure Vessel Code specifies that the carbon-molybdenum-steel pressure vessel receive a final heat treatment after fabrication is completed, it is common practice to heat the vessel slowly to a temperature range of 1100–1250° F, hold at the specified temperature for 1 hr. per inch of thickness and cool slowly in a still atmosphere to a temperature not exceeding 600° F.

SECTION 4: HEAT TREATMENT OF MANGANESE-MOLYBDENUM-STEEL PRESSURE VESSELS— ASME SA-302

SA-302 specification describes the flange and firebox quality plates for the manganese-molybdenum-steel pressure vessels. The majority of the pressure vessels made of plates of this specification use Grade B or 80,000 psi minimum tensile strength plate.

SA-302 plates may be purchased in the hot-rolled or annealed or normalized and stress-relieved condition, depending on the method of fabrication or customer requirements.

Cold Forming of Manganese-Molybdenum-Steel Plates and Heads

Experience indicates that all SA-302 plates should be annealed or preferably be normalized and stress relieved prior to cold forming. The maximum thickness permissible for cold forming is dependent on the radius to which the plate or head is to be bent. This radius is commonly based on producing a maximum outer fiber stretch of 3 per cent in the plate or head, without requiring an intermediate stress-relief heat treatment. Other equally important factors that control the maximum per cent strain on the outer fibers are discussed in Section 1 of this report and shall certainly be considered for manganese-molybdenum steels.

If the outer fiber stretch of the plate exceeds 3 per cent, the cold-forming operation is generally done in two or more stages with the application of an intermediate heat treatment of 1125 to 1250° F when the first stage of cold forming has approached the 3 per cent outer fiber stretch.

Hot Forming of Manganese-Molybdenum-Steel Plates and Heads

The hot forming of SA-302 plates and heads is usually performed in accordance with the general procedure outlined in Section 2 of this report for carbon steel. It is common practice either to anneal or normalize and stress relieve all plates and heads, regardless of thickness, after hot forming before proceeding with further fabrication operations. Hot formed plates are cold formed or "cold sized" to obtain the required tolerance on circularity. No heat treatment is required after this cold forming operation since the outer fiber stretch is usually less than 1 per cent.

Annealing or Normalizing and Stress-Relieving Heat Treatments

The annealing heat treatment[7] may be specified as follows: Heat slowly to 1550–1600° F, hold at this temperature 1 hr. per inch of thickness and slowly

cool to 1200° F, followed by cooling in still air.

Normalizing and stress-relieving heat treatment is often performed because higher impact values are obtained than with the full anneal. The normalizing temperature may vary from 1600 to 1800° F, depending on whether the plates are purchased to regular mill practice or fine-grain steel melting practice. If the plates are purchased to regular SA-302 specification, 1600 to 1700° F is the normalizing temperature often used; whereas, plates purchased to SA-302 made to a fine-grain deoxidation practice may be normalized at a higher temperature range. Since the plate made to fine grain practice is killed with a greater per cent of aluminum than normally used for regular SA-302 material, the higher normalizing temperature will aid in breaking up the "banding" and will increase the tensile strength of the plates and heads. The stress relieving temperature after normalizing may range from 1125 to 1250° F, depending on the tensile strength obtained on the normalized plate. Some fabricators check the microstructure and hardness of the plates and heads after the normalizing heat treatment to be certain that the material is fine grained and the hardness is sufficiently high so that the subsequent stress relief will not lower the tensile strength below the minimum specified for the grade of SA-302 that is being fabricated.

Intermediate Heat Treatments of Manganese-Molybdenum-Steel Pressure Vessels

Any intermediate heat treatments required during the fabrication of manganese-molybdenum-steel pressure vessels, after hot and/or cold forming operations are completed may be satisfied by a temperature range of 1125 to 1250° F. The plate thickness and fabricating procedure used will determine the need for intermediate heat treatments.

Final Heat Treatment of Manganese-Molybdenum-Steel Pressure Vessels

Both Sections I and VIII of the ASME Code specify that SA-302 pressure vessels shall be given a stress-relief heat treatment. Experience indicates that the pressure vessel shall be slowly heated to a temperature range of 1125 to 1250° F, held 1 hr. per inch of thickness, and cooled slowly in a still air atmosphere to a temperature not exceeding 600° F.

SECTION 5: HEAT TREATMENT OF MANGANESE-STEEL PRESSURE VESSELS

This group includes the plate specifications that contain more than 0.90 per cent manganese (except SA-302) as the major alloying element. The following ASME specifications describe plates of flange and firebox quality for use in boilers and other pressure vessels:

SA-202. Chrome-Manganese-Silicon Alloy-Steel Plates for Boilers and Other Pressure Vessels.

SA-225. Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels.

SA-299. High-Tensile Strength Carbon-Manganese-Silicon Steel Plates for Boilers and Other Pressure Vessels.

The general information presented for manganese-molybdenum steel plates in Section 4 of this report on the heat-treatment procedures after cold or hot forming of plates and heads is generally considered by most fabricators to apply to this group of plate materials. The same general requirements for intermediate heat treatments for manganese-molybdenum steel plate in Section 4 are applicable to the steel plates in this group. If the ASME Boiler and Pressure Vessel Code specifies that pressure vessels made of SA-202, SA-225 or SA-299 plates receive a final heat treatment after fabrication is completed, it is recommended that the vessel be heated slowly to a temperature range of 1100 to 1250° F, held at the specified temperature for 1 hr. per inch of thickness and cooled slowly in a still atmosphere to a temperature not exceeding 600° F.

SECTION 6: HEAT TREATMENT OF CHROMIUM-MOLYBDENUM-STEEL PRESSURE VESSELS

ASME Specification SA-301 covers ½ per cent chromium-½ per cent molybdenum and 1 per cent chromium-½ per cent molybdenum steel plates, while SA-357 covers 5 per cent chromium-½ per cent molybdenum steel plates.

ASME Specification SA-387 covers five grades of chromium-molybdenum steel plates ranging from ½ per cent chromium-½ per cent molybdenum to 3 per cent chormium-1 per cent molybdenum. Group I is composed of three grades containing not more than 1.5 per cent chromium and designated A. B and C. Group II consists of two grades containing between 2 and 3¼ per cent chromium and designated D and E. The various grades have the following general chemical compositions:

Grade	Chromium, %	Molybdenum, %
A	½	½
B	1	½
C	1¼	½
D	2¼	1
E	3	1

It will be noted that Grades A and B of SA-387 are comparable to Grades A and B of SA-301. Group II plates and SA-357 plates are intended for mildly corrosive service, as well as for elevated-temperature service.

Heat Treatment of Group I Plates (Grades A, B and C)

SA-387 states the following: "All plates shall be treated to produce grain refinement either by annealing or normalizing and tempering or heating uniformly for hot forming followed by tempering. If the required treatment is to be obtained in conjunction with the hot-forming operation, the temperature to which the plates are heated for hot forming shall be equivalent to and shall not significantly exceed the annealing or normalizing temperature."

Heat Treatment of Group II (Grades D and E) and SA-357 Plates

SA-387 states the following: "All plates in Group II shall be annealed or normalized and tempered by the plate manufacturer. The tempering temperature shall not be less than 1200° F. Heat treatment involving quenching in a liquid medium is not permitted."

SA-357 specifies that all plates shall be annealed.

Cold Forming of Chromium-Molybdenum-Steel Plates and Heads

Chromium-molybdenum-steel plates may be heat treated either by annealing or normalizing and tempering, depending on the particular specification, prior to cold forming. Other equally important factors that control the maximum per cent strain on the outer fibers are discussed in Section 1 of this report and shall certainly be considered for chromium-molybdenum steels. The maximum thickness permissible for cold forming is dependent on the radius to which the plate or head is to be bent. Most fabricators specify that this radius be based on a maximum outer fiber stretch of 3 per cent in the plate or head, without requiring an intermediate stress-relief heat treatment.

If the outer fiber stretch of the plate exceeds 3 per cent, the cold-forming operation is generally performed in two or more stages with the application of an intermediate heat treatment of 1150 to 1300° F when the first stage of cold forming has approached the 3 per cent outer fiber stretch. Heads are generally hot pressed rather than cold formed. The exceptions to this statement will be relatively thin heads of a suitable diameter that no tearing or wrinkling can occur in the head during the cold-forming or cold-pressing operation.

Hot Forming of Chromium-Molybdenum-Steel Plates and Heads

The hot forming of SA-387, SA-301 and SA-357 chromium-molybdenum steel plates and heads is usually performed in accordance with the general procedure outlined in Section 2 of this report for carbon steel. It is common practice either to anneal or normalize and stress relieve all plates and heads, regardless of thickness, after hot forming before proceeding with further fabrication operations. Hot formed plates are cold formed or "cold sized" to obtain the required tolerance on circularity. No heat treatment is required after this cold-forming operation since the outer fiber stretch is generally less than 1 per cent.

Annealing or Normalizing and Tempering Heat Treatments

The annealing heat treatment[7] may be specified in the following manner for the chromium-molybdenum steels:

Heat slowly to 1550–1675° F, hold at this temperature 1 hr. per inch of thickness and slowly cool to 1200° F, followed by cooling in still air.

The normalizing and tempering heat treatments vary widely for the different groups of chromium-molybdenum plates. The normalizing temperature for Grades A, B and C (½ per cent Cr-½ per cent Mo to 1¼ per cent Cr-½ per cent Mo) of Group I of SA-387 may be from 1625 to 1725° F. Although there may be cases, particularly for Grade A, where the normalized plate will meet the tensile requirements without a tempering heat treatment, it is generally considered good practice to apply a tempering heat treatment after normalizing. This tempering heat treatment may vary from 1125 to 1300° F depending on the grade of plate.

The normalizing temperature for Grades D and E of SA-387 (2¼ per cent Cr-1 per cent Mo and 3 per cent Cr-1 per cent Mo) and SA-357 (5 per cent Cr-½ per cent Mo) may be from 1650 to 1750° F. The tempering heat treatment after normalizing may vary from 1200 to 1350° F depending on the grade of plate.

Some manufacturers and fabricators check the microstructure and hardness of the plates and heads after the normalizing heat treatment to make certain that the material is fine grained and the hardness value thus obtained may be used as a guide for the subsequent tempering heat treatment.

Intermediate Heat Treatments of Chromium-Molybdenum-Steel Pressure Vessels

Any intermediate heat treatments required during the fabrication of chromium-molybdenum-steel pressure vessels, after hot- and/or cold-forming operations are completed, may be in the temperature range of 1125 to 1350° F depending on the type or grade of chromium-molybdenum steel plate. The frequency of such intermediate heat treatments will be determined by the specific fabrication procedure and the plate thickness of the pressure vessels.

Final Heat Treatment of Chromium-Molybdenum-Steel Pressure Vessels

Section I of the ASME Code requires that all chromium-molybdenum-steel pressure vessels be stress relieved. Section VIII specifies that all chromium-molybdenum-steel pressure vessels of Grade B or higher alloy content be stress relieved. The exception that Section VIII makes is for Grade A (½ per cent chromium-½ per cent molybdenum) pressure vessels less than 0.58 in. thick in which case no stress relief is required.

It is common practice to stress relieve the pressure vessels in Group I of SA-387 (Grades A, B and C) by heating them slowly to a temperature range of 1150 to 1300° F, holding 1 hr. per inch of thickness at temperature, and cooling slowly in a still air atmosphere to a temperature not exceeding 600° F. The same general practice is followed for stress relieving pressure vessels in Group II of SA-387 (Grades D and E) and SA-357, except the temperature range for stress relieving may be 1200 to 1350° F.

SECTION 7: HEAT TREATMENT OF NICKEL-STEEL PRESSURE VESSELS

Heat Treatment of Low-Nickel-Steel Pressure Vessels—ASME SA-203

Specification SA-203 covers flange and firebox quality plates of 2.00 to 2.75 per cent and 3.25 to 3.75 per cent nickel steels. The various grades have the following general chemical composition

Grade	Carbon, max., %	Nickel, %
A	0.17	2.5
B	0.20	2.5
C	0.25	2.5
D	0.17	3.5
E	0.20	3.5

SA-203 plates may be purchased in the hot-rolled or normalized or normalized and stress-relieved condition depending upon the customer's requirements. Plates over 2 in. in thickness shall be treated to produce grain refinement either by normalizing or heating uniformly for hot work.

The majority of pressure vessels made of plate of this specification are of Grade D material in the normalized condition and stress relieved after fabrication.

The general information outlined in Section 2 of this report on heat-treatment procedures after cold work or hot forming of plates and heads applies equally well to nickel-steel pressure vessels except that some fabricators require a stress-relief heat treatment after normalizing of Grades B, C and E.

The maximum temperature for stress-relief heat treatment should not exceed 1175° F as nickel lowers the critical temperature range.

Heat Treatment of High-Nickel-Steel Pressure Vessels—ASME SA-353

Specification SA-353 covers one grade of 8.50–9.50 per cent nickel-steel plate of firebox quality.

The plates before being fabricated shall be uniformly heat treated to produce grain refinement. This is usually accomplished by a single normalizing consisting of heating to 1600° F, holding at temperature for a minimum of 1 hr. per inch of thickness, but in no case less than 1 hr., and cooling in air; or by double normalizing at 1650 and 1450° F.

Cold Forming High-Nickel-Steel Plate

High-nickel steel in the as-rolled or normalized condition has a tightly-adhering highly-refractory scale which should be removed by pickling or sandblasting. The scale formed by stress-relieving treatments is not sufficiently heavy to affect fabricating operations.

Before cold forming, SA-353 plate should be stress relieved by heating to 1025 to 1085° F, holding at temperature for a minimum of 2 hr. for thicknesses up to 1 in. plus 1 hr. for each additional inch of thickness, and cooled in still air to a temperature not exceeding 600° F. The maximum thickness permissible for cold forming is dependent on the radius to which the plate or head is to be bent but generally plate of SA-353 over 1 in. is hot formed.

If the outer fiber stretch of the plate exceeds 3 per cent, the cold-forming operation is generally done in two or more stages with the application of an intermediate heat treatment of 1025 to 1085° F.

Final Heat Treatment of High-Nickel-Steel Pressure Vessels

The final heat treatment of SA-353 pressure vessels shall consist of heating uniformly to a temperature between 1025 and 1085° F, holding for a minimum of 2 hr. for thicknesses up to 1 in., plus a minimum of 1 hr. for each additional inch of thickness, and cooling in still atmosphere to a temperature not exceeding 600° F.

SECTION 8: HEAT TREATMENT OF QUENCHED-AND-TEMPERED LOW-ALLOY-STEEL PRESSURE VESSELS

Case No. 1204 was approved by the ASME Council on Nov. 15, 1955. This Case gave permission to use quenched-and-tempered alloy-steel plates of firebox quality and alloy-steel forgings in the construction of welded pressure vessels under the rules of Section VIII of the Code with several additional mandatory requirements. Among these mandatory requirements were the following:

1. The maximum thickness of shell and head plates shall be 2 in.

2. The maximum operating temperature shall not exceed 650° F.

3. The requirements of Paragraph UG-84 shall be met for vessels that are to operate at temperatures below −20° F.

4. Chemical composition:

	%
Carbon	0.10–0.20
Manganese	0.60–1.00
Phosphorus, max	0.035
Sulfur, max	0.040
Silicon	0.15–0.35
Nickel	0.70–1.00
Chromium	0.40–0.80
Molybdenum	0.40–0.60
Vanadium	0.03–0.10
Copper	0.15–0.50
Boron	0.002–0.006

5. Heat treatment: The material shall be treated by the material manufacturer to produce the following tensile requirements by heating to not less than 1650° F, quenching in water between 50 and 100° F, and tempering to not less than 1150° F with a holding time of 1 hr. per inch of thickness, but in no case less than ½ hr.

Tensile strength, psi, min.	105,000
Yield strength, psi, min.	90,000
Elongation in 2 in., min., %	17

6. Shell plates shall not be heated for forming to

a temperature higher than 1100° F. Other parts, including heads, that are heated for forming to temperatures over 1100° F shall be heat treated by the manufacturer of the head or part. Forgings shall be heat treated by the manufacturer of the forging. Test specimens prepared from full thickness material in its final heat treated condition, or from full thickness samples similarly and simultaneously treated, shall be taken from any pressure parts that have been heat-treated above 1100° F after forming.

7. When the shell or head thickness exceeds 0.58 in., the finished vessel shall be stress relieved as provided in Paragraph UCS-56(c). The stress relieving temperature shall be between 1000 and 1100° F (at least 50° F below the minimum tempering temperature).

Cautionary Note: Filler metal deposited by nickel-molybdenum-vanadium type of electrodes can become embrittled at the above stress relieving temperature.

The points discussed above only pertain to that portion of Case No. 1204 regarding mandatory heat treatment and fabrication requirements. Many other requirements that must be met in the construction of welded pressure vessels are specified in this Code Case, but these requirements are beyond the scope of this report. The high tensile properties specified for this type of low-alloy steel are obtained by water quenching from a temperature of not less than 1650° F with a mandatory minimum tempering temperature of 1150° F.

SECTION 9: GENERAL METALLURGICAL CONSIDERATIONS IN THE HEAT TREATMENT OF CARBON- AND LOW-ALLOY-STEEL PRESSURE VESSELS

Stout [1] has ably summarized the effects of preheating and postheating of pressure-vessel steels with particular emphasis on the soundness and mechanical properties of welds. He also includes a table containing recommended preheating and postheating temperatures for various carbon contents and thicknesses of the grades of steel commonly used for pressure vessels except for chromium-molybdenum steels. Stout discussed the purpose and effects of preheating and postheating. He stated that preheating is used by the welding engineer because it helps

1. To prevent the formation of cracks in the weld metal or in the heated base metal.
2. To reduce distortion of the weldment.
3. To avoid loss of ductility and toughness in the weld and base metal.

These practical benefits are obtained from preheating by the following actions: (a) the thermal gradient is reduced; (b) the cooling rate is reduced.

Stout stated that postheating is used to produce two principal beneficial effects:

1. Residual stresses can be relieved to a low level.
2. The heat-affected base metal is softened and toughened by the metallurgical changes, and any dissolved hydrogen present is given an added opportunity to escape.

The authors suggest some additional benefits of postheating or stress relieving:

1. It reduces the hardness of the base metal after hot forming or heat treating above the upper critical temperature.
2. It reduces the hardness of the weld metal thus giving added toughness to the weldment.

The reduction of the hardness of the weld metal and heat-affected zones in the base metal is more important for some of the low-alloy steels than for carbon steels and is the primary reason for postheating or stress relieving some of the low-alloy steels at the higher temperature ranges.

The reports prepared by Stout and his associates,[1-6] under the sponsorship of the Materials and Fabrication Divisions of the Pressure Vessel Research Committee, represent the most complete compilation of data for carbon-steel pressure vessels that the authors could find in the literature survey made for the preparation of this report. Some of their conclusions are listed below in the following summary:

1. Two heats of steel were studied—(1) ASTM A-70 or A-285 rimmed steel and (2) ASTM A-201 aluminum-killed steel.

2. The notch toughness of the rimmed A-285 steel was inherently lower than that of the aluminum-killed A-201 steel.

3. Prestraining (up to 10 per cent), welding or heat treatment altered the properties of both A-201 and A-285 steels in the same direction and to about the same extent.

4. Edge preparation—Shearing seriously lowered the notch resistance of both A-201 and A-285 steels. Oxygen cutting had a much less severe effect. Postheating, especially normalizing at 1600° F, was effective in restoring the loss of notch toughness induced by shearing or oxygen cutting. Postheating at 1150° F was noticeably beneficial to the steels but not as effective as normalizing treatment. This was an indication that the loss of notch toughness was due to the heat-affected zone in the case of the oxygen-cut edge or to the plastic deformation of the sheared edges and not due to the small notches introduced by these operations. Machined edges consistently showed excellent toughness with low transition temperatures.

5. Cold forming—Cold working did not seriously lower the ductility or notch toughness of these steels. Heating to temperatures up ot 800° F after cold working produced considerable loss of notch toughness because of strain-aging effects. The rimmed and killed steels showed equal susceptibility to strain aging. Heating to normalizing temperature of 1600° F was necessary to completely erase the effects of cold working.

6. Welding—Welding reduced notch touchgness or raised the transition temperatures of the carbon steels more than cold working and strain aging. Cold-worked specimens were only slightly less notch tough after being welded than were un-

strained specimens after welding. Thus the effects of cold working and welding did not appear to be additive. Postheating to 1100° F or above restored much of the loss of notch toughness due to welding.

7. Transition temperature tests on spherically hot- and cold-pressed specimens indicated that cold pressing definitely raised the transition temperature, whereas hot pressing resulted in transition temperatures that were equal to or better than the unpressed rimmed (A-70 or A-285) or aluminum-killed (A-201) steels.

These conclusions were based on laboratory test data and were the results of a five-year program at Lehigh University.

The possibility of drawing definite conclusions about the effects of fabrication operations on service properties from these laboratory tests is hampered by the fact that there are factors which enter into the manufacture of pressure vessels which could not be incorporated into these laboratory tests. However, these tests do provide information about the direction and extent of the effects that cold forming and welding may produce in carbon-steel pressure vessels of A-70 or A-285 rimmed steel and A-201 aluminum-killed steel.

Brittle Fracture

Considerable attention has recently been focused on "brittle fractures," particularly with regard to failures that have occurred in a brittle manner at temperatures above which the material had been considered satisfactory for the intended applications. It was found that some of the steels investigated may have a transition temperature as high as +100° F, depending on various metallurgical factors such as deoxidation practice, composition, rolling practice and subsequent heat treatment. Armstrong [8] and co-authors discussed four conditions that control the tendency for steel to behave in a brittle manner. These conditions include (1) high stress concentrations—i.e., notches, nicks, scratches, internal flaws or sharp changes in geometry; (2) high rate of straining; (3) a low operating temperature; and (4) several metallurgical factors.

The metallurgical factors, including deoxidation practice, composition, rolling practice and subsequent heat treatment, influence that transition temperature of steel which, under the worst conditions, may be above 100° F or, under the best conditions, below −200° F.

The transition from ductile to brittle behavior of a steel is generally expressed in terms of temperature. McGeady [9] reports on carbon-steel pressure vessels in a temperature range from +32 to −50° F, with particular emphasis on transition temperature behavior. He states that on failed pressure vessels, failure has been generally associated with brittleness of the steel at operating temperature at the time of failure. Pellini [10] discusses three critical transition temperatures and the comparative values as determined by the Charpy V-notch test, the crack-starter explosion test and the drop-weight test. He also points out that there are four possible paths along which brittle fracture may propagate. These are: (1) the plate, (2) the heat-affected zone, (3) the fusion line and (4) the weld metal. Propagation through any given path becomes possible only if the service temperature is below the critical fracture temperature for that zone. Transition temperatures determined by notch tests furnish valuable information for design, but as yet these data are qualitative because test data for only a few steels have been correlated with actual service performance.

The above references [8, 9, 10] are only a few of many reports and papers that have been written on the subject of "ductile and brittle fractures." It is recognized that accelerated cooling, such as spray quenching or even dip quenching, from above the upper critical temperature followed by stress relieving or tempering heat treatment is beneficial in lowering the temperature at which a material becomes notch sensitive or gives a "brittle" fracture. The practical application of an accelerated cooling treatment, such as spray or dip quenching to pressure vessels is a problem to many fabricators. *Good design* and *excellent workmanship* are just as important in the life of a pressure vessel as *high notch toughness* in plate materials and weld metals. The ASME Boiler and Pressure Vessel Code Committee has recently appointed a Special Committee on Brittle Fracture to study and correlate the data obtained on this subject with regard to boiler and pressure-vessel components.

High-Temperature Properties

Romer and Newell [11] discuss the significance of the time factor in testing in relationship to long-life high-performance steam-generating equipment as well as the general effects of metal oxidation from steam and combustion atmospheres. The relative merits of long-time creep tests and stress-rupture tests are considered. A résumé is given of field experience on carbon and alloy steels. It was emphasized that the metallurgical stability of steels is important in maintaining creep strength and is necessary to prevent severe modification of mechanical properties through effects such as spheroidization of carbide phase, graphitization or formation of sigma phase in highly alloyed steels. However, the formation of sigma phase is not a problem in the carbon and low-alloy pressure-vessel steels.

Wylie and Thielsch [12] prepared an interpretive engineering statement of the present knowledge on the creep and stress-to-rupture characteristics of pressure-vessel steels. These authors pointed out that, in the design of pressure vessels for service applications at elevated temperatures, various factors may impose limitations on the service life. Thus, such factors as creep and stress-rupture, fatigue, surface oxidation, structural changes within the material, corrosion and others have to be considered in the selection of materials and in the de-

sign of pressure vessels. Among these, creep and stress-rupture represent two of the more important factors.

There is some information in the British literature to the effect that temperatures of 1300–1350° F are not beneficial to the long-time characteristics of certain chromium-molybdenum steels. One authority in Great Britain states that, in general, short-time heatings at these temperatures tend to break down the carbide structure which influences the long-time stability of these steels. However, there seems to be general disagreement among the authorities in the United States as to any harmful effects of the 1300–1350° F stress-relieving heat treatment; so, until such time as definite harmful effects are shown to be due to this heat-treating range, many fabricators will continue to use the temperature range of 1300–1350° F for final heat treatment of some of the grades of chromium-molybdenum pressure vessels.

Chromium-Molybdenum Weld Properties

Carpenter and Floyd [13] have presented the latest data on low-carbon (0.05 per cent max.) chromium-molybdenum electrodes for welding materials containing from ½ to 5 per cent chromium and ½ to 1 per cent molybdenum. This paper includes the effect of carbon on chromium-molybdenum welds, coating characteristics of these E-XX15 low-carbon limecoated chromium-molybdenum electrodes, selection of electrodes, weld groove design and preparation, preheat, welding technique and postweld heat treatment. The room-temperature mechanical properties of these welds in the as-welded condition as well as stress relieved at different temperatures in the range of 1150 to 1350° F have been presented. Data on tensile tests conducted at temperatures of 800 to 1100° F on the various types of low-carbon chromium-molybdenum weld metals in both the as-welded and 1350° F postweld heat-treated conditions are included in the paper. Stress rupture strength of these weld metals from tests conducted at temperatures of 1000 to 1200° F is compared to stress rupture data on wrought materials of similar chemical compositions. Some general data are also presented on 7 per cent chromium-½ per cent molybdenum and 9 per cent chromium-1 per cent molybdenum weld deposits. Other topics of general interest included in this paper are studies of carbon migration and temper brittleness of low-carbon chromium-molybdenum weld metals.

SECTION 10: SUBJECTS FOR FURTHER INVESTIGATION AND STUDY

In view of the lack of information in the literature regarding the fabrication and heat treatment of low-alloy plate materials, it is apparent that there are many subjects that should be investigated to give the fabricators essential basic information that is necessary for further progress in the fabrication of pressure vessels. There are also many controversial subjects that have been investigated through the use of small laboratory specimens but have not been proven by shop practices.

Some of the questions that should receive serious consideration in further pressure vessel investigations are the following:

1. May lower stress-relieving temperatures be used for low-alloy-steel pressure-vessels than now employed by most fabricators?

2. Can sufficient data be gathered for the ASME Boiler and Pressure Vessel Code Committee to permit the relaxation of the requirements for Section I pressure vessels to the extent permitted for Section VIII pressure vessels?

3. May the postheat treatment (stress relief) of low-alloy-steel pressure vessels be eliminated in the following plate materials for wall thickness less than 0.58 in.? SA-301 Grade B or SA-387 Grade B (1 per cent Cr-½ per cent Mo); SA-387 Grade C (1¼ per cent Cr-½ per cent Mo); and SA-302 (Mn-Mo).

4. What are the effects of the different types of heat treatment on the notch toughness of low-alloy pressure-vessel steels?

5. What are the effects of time and temperature of postheat treatment on the notch toughness of low-alloy pressure-vessel steels?

6. What is the relative importance of residual stresses compared to softening effects on hard microstructures in postheat treatment (stress relief) of low-alloy pressure-vessel steels?

7. What are the maximum limits (maximum outer fiber stretch) that can be safely used in cold forming carbon-steel and low-alloy plates without requiring intermediate heat treatments?

8. What are the effects of postheat treatment (stress relief) at 1350° F on the creep and stress rupture properties of chromium-molybdenum pressure vessels?

A task group was appointed approximately two years ago by the ASME Boiler and Pressure Vessel Code Committee to make recommendations on "Correlation of Stress Relieving, Radiographing and Welding Requirements."

With regard to Questions 1–3, the Subcommittee on Unfired Pressure Vessels has studied the Task Group's recommendation and approved revisions in Paragraph UCS-56 and has proposed a new Table UCS-56 of Section VIII, "Rules for Construction of Unfired Pressure Vessels," on heat treatment requirements for carbon and low-alloy steels that relax some of the restrictive requirements on the low-alloy steels that are not classified as air-hardening steels. The main ASME Boiler and Pressure Vessel Code Committee is considering these revisions at the present time. Meanwhile, the Subcommittee on Power Boilers is considering the report of the Task Group with regard to revisions of Section I, "Rules for Construction of Power Boilers."

In consideration of Questions 4, 5 and 8, the authors' company has development programs in progress on these topics. Reference 13 contains some pertinent data on Question 8.

REFERENCES

1. Stout, R. D., "The Preheating and Post-heating of Pressure Vessel Steels," *The Welding Journal,* 32 (1), Research Suppl., 14-s to 22-s (1953).
2. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., and Johnston, B. G., "Composition and Property Variations of Two Steels," *Ibid.,* 28 (5), Research Suppl., 227-s to 235-s (1949).
3. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., and Johnston, B. G., "Effect of Plastic Strain and Heat Treatment," *Ibid.,* 28 (8), Research Suppl., 337-s to 353-s (1949).
4. Tör, S. S., Ruzek, J. M., and Stout, R. D., "The Effect of Fabrication Processes on Steels Used in Pressure Vessels," *Ibid.,* 30 (9), Research Suppl., 446-s to 450-s (1951).
5. Tör, S. S., Stout, R. D., and Johnston, B. G., "Further Tests on Effects of Plastic Strain and Heat Treatment," *Ibid.,* 30 (11), Research Suppl., 576-s to 584-s (1951).
6. Tör, S. S., and Stout, R. D., "Investigations of Effect of Fabrication Operations Upon Pressure Vessel Steels," Welding Research Council, Bull. No. 11 (May 1952).
7. "Suggested Heat Treatment and Forming Data for Boiler and Pressure Vessel Steels," *The Welding Journal,* 29 (12), Research Suppl., 622-s to 623-s (1950).
8. Armstrong, T. N., Kahn, N. A., and Thielsch, H., "Transition from Ductile to Brittle Behavior in Pressure Vessel Steels," *Ibid.,* 31 (8), Research Suppl., 371-s to 380-s (1952).
9. McGeady, L. J., "Transition Temperature Behavior of Pressure Vessel Steels," *Ibid.,* 34 (1), Research Suppl., 1-s to 11-s (1955).
10. Pellini, William S., "Notch Ductility of Weld Metal," *Ibid.,* 35 (5), Research Suppl., 217-s to 234-s (1956).
11. Romer, J. B., and Newell, H. D., "The Creep and Stress-Rupture Testing of Steam-Boiler Materials," Preprint No. 50 A-129, ASME (Nov. 28, 1950).
12. Wylie, R. D., and Thielsch, H., "Creep and Stress-Rupture Properties of Pressure Vessel Steels," *The Welding Journal,* 31 (1), Research Supp., 11-s to 19-s (1952).
13. Carpenter, O. R., and Floyd, C., "Important Considerations for the Welding of Chromium-Molybdenum Steels," West of Scotland Iron and Steel Inst.—Symposium on the Application of Low-Alloy Steels for Welded Pressure Vessels, presented Oct. 19, 1956.

A novel heat exchanger applicable to thermal energy transfer between two gases has recently been developed by Wellington Laboratory of Convair. The two gases flow in a longitudinally divided cylindrical duct. A rotating matrix in the duct, driven by the gas flow or by an external power source, transfers the energy from the hot stream to the cold stream. The design is said to offer high efficiency with low core weight.

* * * *

A new concept in ship structural design is incorporated in plans for a Swedish tanker developed by Transoil-Rederierna. In this design the bulkheads are no longer transverse; instead, they are V-shaped with the point of the V aft, angling back at about 45 degrees from the transverse line. The deck beams are also constructed in a V-shape, angling forward. The primary advantage claimed is reduction in peak shear stresses due to partial loading of the tanks. The designer is presently negotiating for the construction of a 45,000 ton tanker to this arrangement, which has been approved by Lloyd's Register.

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Never have our opportunities and our responsibilities been greater.

ROSS E. MORRIS and ROBERT R. JAMES

A METHOD FOR WATERPROOFING BONDED ELECTRICAL-RESISTANCE STRAIN GAGES

THE AUTHORS

Ross E. Morris, since 1939 civilian in charge of the Navy's rubber laboratory, Mare Island Naval Shipyard, Vallejo, California, was graduated from the California Institute of Technology with a M.Sc. in chemical engineering in 1932. After receiving further education in rubber chemistry at the University of Akron, he served in various technical capacities in the Goodyear Tire and Rubber Company plants in Akron, Ohio, and Los Angeles, California, and was chief chemist of the Kelly Springfield Tire Company in Cumberland, Maryland, before entering the employ of the Navy. He has been a director of the Rubber Division of the American Chemical Society and president of the Northern California Rubber Group. He is the author or co-author of 50 published articles on rubber technology.

Robert R. James has been a section head in the Mare Island rubber Laboratory since 1941. He was educated at Compton Junior College, University of Southern California and University of California, receiving a degree in chemistry from the latter institution. He was employed at the Goodyear Tire and Rubber Company, Los Angeles, California, for 12 years, and was chief compounder of that organization before coming to Mare Island. Mr. James was also a director of the Rubber Division of the American Chemical Society, and was successively secretary and vice president of the Northern California Rubber Group. He is the author or co-author of many published reports on the technical aspects of rubber.

THE BONDED electrical-resistance strain gage is a device for measuring the compression or extension of a metal surface subjected to stress (1). The gage is cemented to the metal surface. The strain in the surface resulting from the stress causes a very small but proportional change in the electrical resistance of the gage. By measuring the change in resistance of the gage, the strain in the metal surface can be accurately determined.

The bonded strain gage has found wide application in engineering practice because, for the first time, it has enabled the engineer to measure easily the strains existing in a composite structure. The gage, however, has a drawback from the standpoint of measuring strains in marine structures; it cannot be used under water without special protection. Since the electrical resistance of the gage is its critical feature, penetration of water into the gage makes it worthless.

Several methods for waterproofing strain gages have been developed in the past and used with varying degrees of success (1, 2, 3). Most of the failures of gages waterproofed by these methods have probably been due to lack of adhesion between the jacket of the cable carrying the extension leads and the waterproofing material, although such failure could not have occurred with the arrangement proposed by Koch, Boiten, et al (3). The latter arrangement employs a rubber cap vulcanized to the jacket of the cable carrying the lead-in wires to the gage.

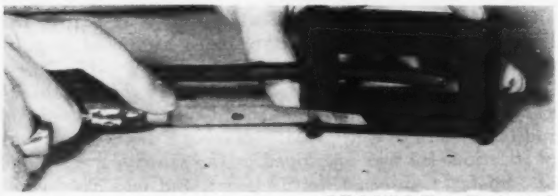
The purpose of this paper is to describe a new method for waterproofing strain gages. This method has some similarity to Boiten's method, but was in fact developed before the latter method came to the

authors' attention. The authors' method, as will be shown later in the report, has been proved suitable for use with hydraulic pressures, whereas Boiten made no claim in this regard. Further comparison of the two methods will be made at the end of this report.

OUTLINE OF METHOD

The authors' method consists in brief of the following steps:

1. Mold a hollow rectangular neoprene dam on the neoprene jacket of a cable carrying three conductors. A neoprene dam being trimmed after molding is shown in Figure 1.
2. Cement the active strain gage to the surface of the structure being tested. A strain gage cemented to a steel surface is shown in Figure 2.
3. Cement a temperature-compensating strain gage to a small plate of the same metal as the structure being tested.
4. Cement the neoprene dam to the surface of the structure being tested in such a manner that the active strain gage is centered in the hollow dam. This arrangement is shown in Figure 3.
5. Solder the leads from the active strain gage to two of the conductors from the cable.
6. Solder the leads from the temperature-compensating strain gage to two of the conductors from the cable. One of these conductors shall be common to both gages, as shown in Figure 4.
7. Partially fill the hollow of the dam with electrical insulating mastic. Place the plate with the temperature-compensating gage on the mastic and fill the hollow with mastic flush with the top of the dam. The filled dam is shown in Figure 5.



Official U.S. Navy Photograph

Figure 1. Neoprene dam being trimmed after vulcanizing to cable cover.

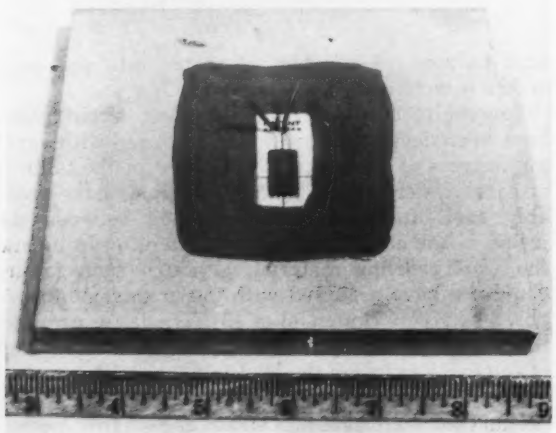


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Figure 2. Strain gage cemented to steel surface.

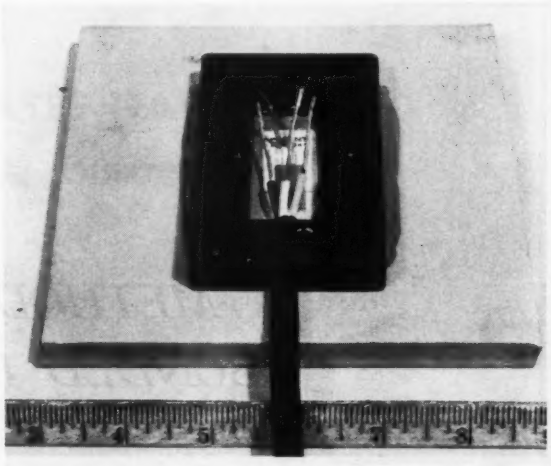

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Figure 3. Neoprene dam cemented to steel surface around strain gage.

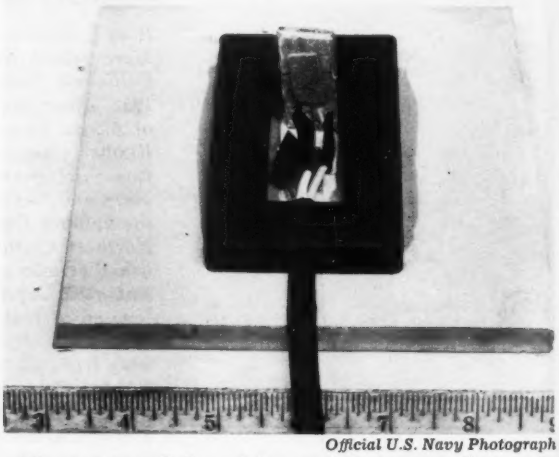

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Figure 4. Installation of temperature-compensating strain gage.

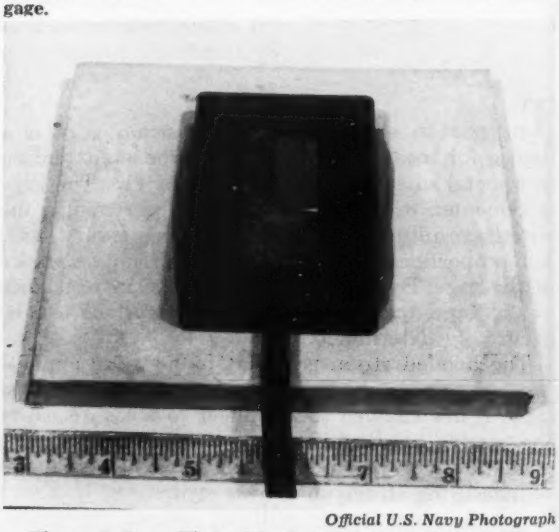

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Figure 5. Dam filled with electrical insulating mastic.

8. Cement a sheet of neoprene over the top of the dam to cover the electrical insulating mastic and strain gages. The completed waterproof covering is shown in Figure 6 and a sketch of the vertical cross section of the assembly is shown in Figure 7. The waterproof covering should not be subjected to tension or shear strains for at least 48 hours after assembly. In static applications, the waterproof strain gage may be immersed immediately in water.

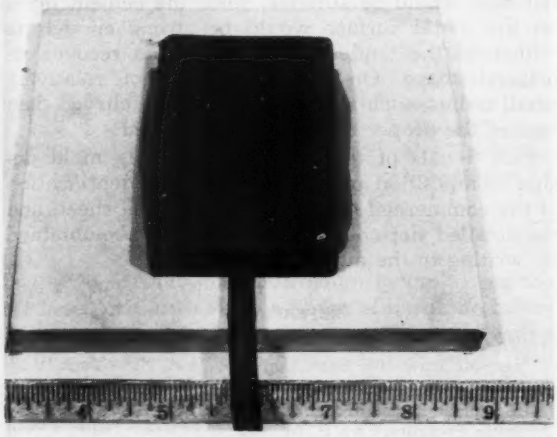

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Figure 6. Completed waterproof covering for strain gage.

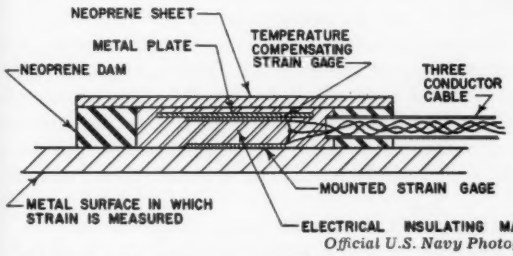

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Figure 7. Vertical cross section of waterproof covering assembly.

RESULTS OF TRIALS

A bonded electrical-resistance strain gage is not suitable for measuring strains unless its resistance to ground is greater than 1000 megohms. Several bonded strain gages were waterproofed following the described procedure, and were subjected to 500 psi water pressure continuously for four months. At the end of this time, the resistance of the individual gages were found to be unchanged, and the resistance to ground of each gage was found to be over 1000 megohms. This proved that gages waterproofed by the new method may be used safely under hydraulic pressures.

Since it may be desired to use strain gages on surfaces over which water is flowing, the following test was performed. A triangular steel plate provided with a clevis at its apex for towing and a stabilizing fin was prepared. Two waterproofed bonded strain gages were attached symmetrically to the top surface of the plate and two to the bottom surface. Views of the assembly are given in Figures 8 and 9. The plate was towed behind a small boat for 2½ hours at 15 knots. During this period the plate rolled and dove violently in the wake of the vessel, thus subjecting the neoprene dams around the gages to severe shearing forces. After this experience the resistance of the gages were found to be the same as before the test, and the resistance of the gages to ground were still over 1000 megohms.

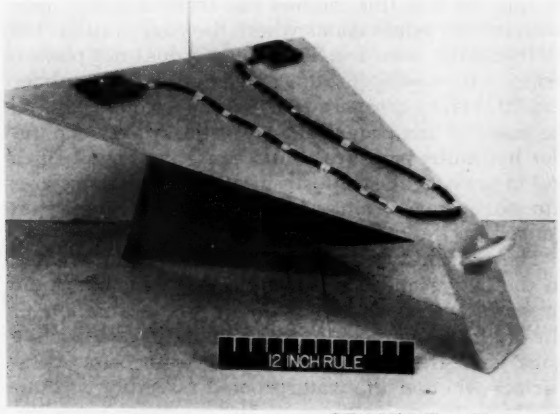

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Figure 8. Top view of tow plate showing waterproof strain gages.

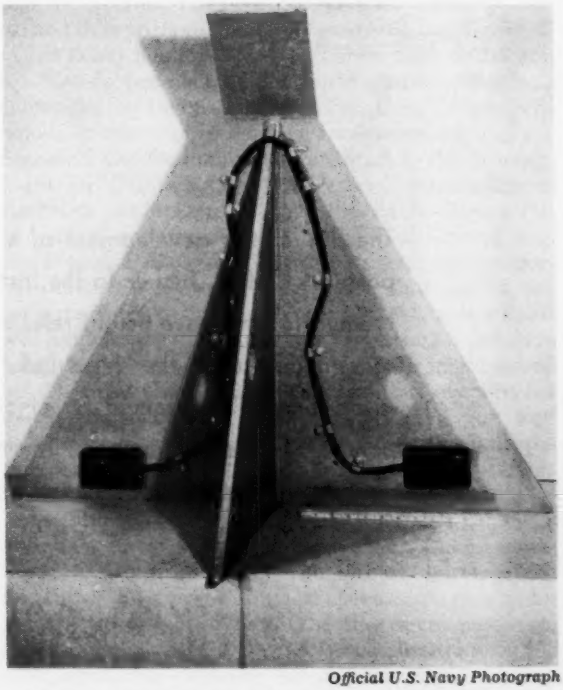

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Figure 9. Bottom view of tow plate showing waterproof strain gages.

COMPARISON WITH BOITEN'S METHOD

As mentioned above, Boiten's method of waterproofing strain gages is similar to the method described here. He proposes the use of a rubber cap vulcanized to the insulation on the conductors. The leads from the strain gage are soldered to the ends of the conductors inside the cap. A bag of silica gel to absorb water vapor is placed in the cap, and the edges of the cap are cemented to the metal surface around the strain gage. Boiten does not suggest the use of his method for applications involving hydraulic pressure or water flow.

The authors have not tried Boiten's method, but it appears that this method has disadvantages, particularly for applications where the gage is subjected to hydraulic pressure. This method does not place a temperature-compensating gage within the rubber cap, therefore a separate installation would have to be made of this gage. Collapse of the rubber cap under hydraulic pressure would cause the bag of silica gel to press against the strain gage and perhaps create extraneous strains in the gage besides the strain caused by the movement of the metal surface.

The possibility of additional strains being created in the active and compensating gages by hydraulic pressure was considered during the evaluation of the authors' method. It was found that the active gage gave the correct values of strain on a metal surface whether the waterproofed assembly was under atmospheric pressure or 500 psi water pressure. Evidently, the temperature-compensating gage also acts as a pressure-compensating gage, or the electrical insulating mastic acts like a true fluid and transmits the water pressure equally in all directions to both gages so that no foreign strains are introduced.

USE ON CURVED SURFACES

It should be mentioned that this method has only been used for waterproofing strain gages installed on essentially flat surfaces. There is no reason, however, why it should not be usable on curved surfaces. On curved surfaces of considerable radius the flat dam would be suitable, since the cement layer on the metal surface would be strong enough to withstand the tendency of the dam to recover its original shape. On curved surfaces of relatively small radius, such as one foot or less, a curved dam having the proper radius should be used.

Full details of this method—including mold design, composition of the dam rubber, identification of the commercial cements and neoprene sheet, and the detailed steps of the procedure—can be obtained by writing to the authors.

REFERENCES

(1) *The Strain Gage Primer*, by C. C. Perry and H. R. Lissner, McGraw-Hill Book Company, Inc., New York, 1955.

(2) "Performance of Waterproofing Compounds applied to Electrical Resistance Strain Gages subjected to Hydrostatic Pressure," by P. M. Palermo, Navy Dept., David W. Taylor Model Basin Report 760, Dec. 1954.

(3) *Strain Gauges—Theory and Application*, by J. J. Koch et al, Philips Technical Library, Eindhoven-Holland, 1952.

The design and development of a shipborne wave recorder has been reported by M. J. Tucher to the Institution of Naval Architects. The measurement of the wave height relative to the ship is recorded by a pressure sensing device on the ship's hull. The measurement of the vertical ship displacement is obtained by electrical integration of the vertical component of an accelerometer. The two quantities, added together, give a continuous wave height measurement above an arbitrary datum plane.

"U.S. NAVAL INSTITUTE PROCEEDINGS"

TANKER OPERATION AND MANAGEMENT

ACKNOWLEDGEMENT

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THE transportation of petroleum in bulk over the sea lanes of the world is a phase of maritime enterprise of comparatively recent origin. Considering the significance of petroleum in our modern world, it is surprising to learn that the first ship designed expressly to carry oil in bulk, rather than in wooden barrels or metal drums, was built as recently as 1886. This was the steamer *Glückauf,* built in England for W. A. Riedemann, a German shipowner. She had a deadweight of only 3,020 tons, not impressive when compared to the giant tankers of the present, but important as the prototype of the world's tanker fleet. Like them, she had steamdriven pumps located in a room separated from the cargo tanks by steel bulkheads, and her engine-room was cut off from the tank area by twin bulkheads forming a cofferdam, a pattern of construction which has not altered with the years.

In the seventy years which have elapsed since *Glückauf* was launched, the increase in number, size, and speed of bulk oil carriers has been steady and remarkable, particularly since the end of World War I. In 1920, for example, the possibility of the so-called supertanker was only dimly envisioned. One or two daring owners built ships of about 22,000 tons, but most operators were content with the 12,000-ton ships, the accepted standard of that time. By the end of the decade, however, it was possible to find oil carriers of about 16,000 tons dead-weight, but their construction was considered to be a rather risky venture. Almost without exception the tankers had a speed of eleven knots.

It was World War II, with its vast distances and almost insatiable demands for petroleum products, which brought about a new standard for tankers. The construction by the United States government of hundreds of T-2 tankers, with a deadweight of about 16,600 tons and a service speed of 14½ knots, proved conclusively that the larger and faster ships were economically justifiable. Although a temporary reversion to the smaller and slower ships occurred immediately following the war, by 1947 a number of big ships was on order. The first were in the 25,000 to 27,000 tons deadweight class, but they were followed rapidly by ships of 32,000 tons and later by vessels of 45,000 to 47,000 tons deadweight. Today, few tankers are built which have capacities of less than 16,000 tons, and these are all designed for special services. Speeds, too, have increased steadily, and sixteen knots is accepted as normal. *World Glory,* of 45,500 tons deadweight, has a speed of 17.3 knots, and *W. Alton Jones,* of 39,000 tons capacity, has turned in reports of speeds in excess of that figure.

The latest available statistics show that at the end of 1954, 55 per cent of the world's tanker fleet was controlled by independent owners. Over 33 per cent belong to major oil-producing companies, such as the Standard Oil Company (New Jersey), the Socony-Mobil Oil Company, and the Texas Company among American organizations, and the Anglo-Saxon Petroleum Company (Royal Dutch Shell Group) and the British Petroleum Company, among foreign corporations. Since world production and use of petroleum continues to rise, it is likely that tanker fleets will have to grow if they are to serve the oil industry adequately, a situation which has been underscored by the Suez Canal crisis. Tankers now account for more than a quarter of the world's merchant tonnage, as compared with 17 per cent in 1939, and the proportion of tankers to all other types of shipping is being heightened each year.

As company fleets have grown larger, the problems of management of the individual vessels in those fleets have multiplied. Voyages are of shorter duration now, because of higher speeds; cargoes grow steadily larger as a result of the development of super-tankers with deadweight capacities up to 50,000 tons; operating expenses for the big ships may approximate $5,000 a day; and the pressure to empty the ships at destination and get them back quickly to

loading ports has heightened. Maintenance of the physical plant, planning for the proper and expeditious handling of vessels in port, procurement of competent officers and crew, and continuing the time-honored personal relationship between owner and shipmaster, have become matters demanding for their successful handling the utmost skill and wisdom on the part of tanker owners and operators.

Tanker ownership today is one of the most complex activities in international shipping. This complexity comes partly from the fact that the unceasing growth of the petroleum industry, with its changing patterns of operations, has necessitated a parallel increase of speed, flexibility, and efficiency in transoceanic transportation. Not only must tanker owners handle the daily problems arising from ships that trade actively over the world's sea lanes, but simultaneously they must work to anticipate the long-range developments which will be forced upon them by progress of the oil industry. When oil producers present new requirements for transportation, tanker operators must respond with solutions. This intermingling of present and future has its consequences, for it exerts a decisive and continuing influence upon all decisions that are made at the higher levels of management.

Viewed from these levels, the transportation of oil in bulk is basically only another form of shipping activity. Since the actual carriage of oil always has been a highly specialized operation, it might appear to the casual observer that tanker management is similarly specialized and is concerned only with problems peculiar to itself. Not so. Tankers must be built, maintained, and repaired; they must be manned, and working conditions must be determined; schedules and operational details must be set, under the same conditions as, and in competition with, other forms of shipping enterprise. Tankers are affected by the same bottlenecks and the same shortages as are dry-cargo and passenger ships. As the size of individual ships increases and the number of units in company fleets grows, there is a corresponding multiplication of daily operating problems. (The British Petroleum Company owned 148 ships and had 142 ships under charter in 1955.) Consequently, competition between oil-carriers and other shipping arises which demands progressively greater attention from tanker management.

The significance of this statement will be seen in the following illustrations. The larger ships of today's tanker fleets are equipped with more highly-powered and complex engines and require more skillful marine engineers. The major passenger vessels like-wise benefit from the advances in naval architectural and engineering knowledge and likewise seek the most desirable mariners. More elaborately equipped repair yards are needed for overhaul and service by both tankers and passenger ships, and some competition for the use of these yards inevitably arises. The giant tankers of today are exceeded in size only by superliners, and like the latter can be drydocked in only a relatively small number of shipyards. It will readily be seen that the failure by tanker management to keep these factors under consideration could easily lead to difficulties.

Aside from possible competition for the use of existing facilities in working out their daily problems, there are many other problems which tanker managers face in common with all shipping managers. However, the nature of oil cargoes, the special type of terminals required for loading and discharging them, and the direction of the flow of traffic are peculiar to the tanker business.

Fundamentally then, the problems underlying ship operation are common to all forms of sea transport. Loss of time in port and the need to make ballast—or nonrevenue-producing—voyages are equally the enemies of the dry-cargo tramp, the passenger liner, the specialized carrier, and the tanker operator, and for exactly the same reasons.

ORGANIZATION OF THE TANKER INDUSTRY

To appreciate the particular problems of the tanker industry, it is essential that its relationship to the oil industry be understood. The demand for overwater transportation of petroleum—crude, refined, or residual—derives from the production, refining, and marketing branches of the oil companies, any one of which may have valid reasons for requiring the services of tankers. Sales are consummated by the marketing division, frequently on condition that the ultimate consumer receive the desired type and quantity of product at a time and place satisfactory to him. Thus it often develops that the transportation division may be asked to move crude oil from a production center in the Persian Gulf to a refinery in New England; or it may be necessary to deliver aviation gasoline to a tank-farm half-way around the world. These often conflicting demands for tankers create many intricate problems for the marine department.

All the foregoing forms of sea-movement of petroleum are harmonized by the transportation division. Some oil companies accomplish this coordination through wholly-owned subsidiaries. Such a subsidiary is the Esso Shipping Company, a member of the Standard Oil Company (New Jersey) "family." Other oil companies set up marine departments within the parent concern, as in the case of The Texas Company. In England, the British Tanker Company serves the needs of the British Petroleum Company. The Marine department of the Anglo-Saxon Petroleum Company supervises the transportation of oil for the Royal Dutch Shell Group. Regardless of how coordination is arranged, the ships are assigned to the division requiring their services and a price is charged for their use, based on current prices on the open market.

It here becomes appropriate to inquire where these great organizations obtain the ships they require. Slightly less than half the world's tanker tonnage is owned and operated by oil companies. The balance

(excluding those tankers which are owned and operated by governments for their own purposes) belong to what are usually called "independent" tanker owners. These independents own and manage ships available for world-wide trading and are quite accurately described as "tramp tanker" owners. Until relatively recently, these owners operated tankers exclusively, but now many dry-cargo tramp and liner companies have added tankers to their established fleets. This development has been sponsored in England by the major oil companies, which have encouraged shipowners to expand their activities to include the transportation of petroleum in bulk. The gigantic Peninsular & Oriental Steam Navigation Company announced in 1955 that it was building a score of tankers. In Norway, the cargo-liner fleets of Wilhelmsen and Leif Høegh have been augmented by a substantial number of bulk oil carriers. Despite the growth of oil-company owned fleets, the independent owners appear to be able to maintain their present proportion of tankers in the world fleet.

Tankers belonging to the independent fleets are made available to the oil companies through the familiar forms of time charter, consecutive voyage charter and single-voyage charter. Time-chartered vessels are at the complete disposition of the oil company and may be integrated into long-range planning in the same manner as elements in the fleet owned by the company. It is not practicable for oil companies to meet all needs with time-chartered vessels. A considerable number of ships always is needed to fill marginal requirements on a voyage-charter basis. The value of this marginal tonnage is well appreciated in the oil industry. The independent tanker owners specialize in providing such marginal shipping, and their skill in timing and placing their vessels to fill oil-company needs is rewarded quite often by substantial charter rates.

Prior to 1939, the generally accepted practice of a typical oil company was to own about 65 per cent of the tonnage required to transport its petroleum. Of the balance, 25 per cent was obtained on the open market through long-term time charters. The remaining 10 per cent was covered by voyage (so-called "spot") charters. Since the end of World War II, however, the expansion of the oil industry has been on so great a scale that modifications of this policy have been forced upon the oil-producing companies. Fleets owned by producers now cover only about 55 per cent of company transportation needs, and dependence on "spot" coverage is being reduced to about 5 per cent.

The consequences entailed by these shifts of policy are noteworthy. The growth in the number of ships in company-owned fleets needed to maintain the same proportion of transportation requirements, when measured against the vast upsurge in production, has made it difficult—perhaps impossible—to continue personal contact between management and the individual ships. For instance, if a pre-war fleet numbered twenty ships, each of them enjoyed a certain personality and was considered as a particular entity. Today, to do relatively the same job of hauling petroleum, the fleet might have to consist of forty ships. But, to preserve the same standard of close managerial contact that existed in pre-war days, it might be necessary to establish an elaborate and expensively top-heavy organization of supervisors, expediters, and "vessel operators." In other words, management would have to set up a number of sub-fleets, each under a supervisory team. This would be a cumbersome and costly expedient.

The only practical alternative is to turn to time-chartered vessels. Their use provides what is at present regarded as the most satisfactory means of preserving contact between management and ships. The owner of the chartered vessel may possess only four or five ships, in which event he remains the operating chief of his fleet. Problems are less difficult for him to solve, in many cases, because they present themselves on a small scale. The charterer, for his part, has obtained a vessel which can be integrated into the company fleet insofar as employment is concerned. An important consideration also is that the cost of management is reduced, since the vessel always is chartered at the market—or the competitive —rate.

"Spot" coverage remains a vital but necessarily marginal type of activity. The availability of a ship for one or more voyages between ports at a time when there is a momentary surplus of cargo, or a shortage of company-controlled ships, is highly desirable to every oil company, since deliveries to refineries and distribution points must be maintained on schedule. Even though the price of the ship may be comparatively high when measured against a time-chartered vessel, the convenience of being able to use a ship at just the time it is needed, and only for that period, often offsets any monetary loss. The requirement for such temporary tonnage is estimated to amount to about five per cent. This means that a large number of ships regularly must be procured from the independent tanker owner, and his success is assured so long as the demands for transportation of oil products remain at their present or anticipated levels.

Another interesting development in chartering tankers has arisen in these post-war years. A number of the larger oil companies have made arrangements with independent tanker shipowners to time-charter ships for ten, fifteen, or twenty years, with the charter becoming effective on delivery of the vessels by the builders. Using the charter as collateral, the shipowner has been able to obtain the necessary financial support to permit him to construct the ships. The owner assumes full operational responsibility for the ships, and the charterer is guaranteed a vessel which will meet his needs and be available to him just as though it were owned by the oil company. The independent tanker owner is placed in the *de facto* position of being a partner in the oil company but is not required to expand his fleet to

proportions which may be unwieldy. To the oil company, the advantage of such an arrangement is obvious, since it is responsible only for loading and unloading the vessel and providing appropriate sailing orders.

FUNCTIONS OF TANKER MANAGEMENT

The primary reason an oil-company owns tankers is to provide efficient ocean transportation at competitive rates on schedules which are most satisfactory to the needs of the company. Proper organization, coupled with appropriate delegation of responsibility, is essential to attain these objectives. It therefore is appropriate to review here the various aspects of tanker management, in the technical sense of that term, as distinguished from operational activity.

First, there are many technical factors that must be considered in the design and construction of new tankers. Although the war-built T-2 type tanker retains its predominant place in contemporary tanker fleets (there are still about 250 such ships under American registry), the capabilities of this class of ship are limited. Gradually the T-2 is being superseded by larger, faster, and more flexible vessels. These new ships are either in the "medium" category of 18,000 to 20,000 tons deadweight, with a minimum speed of 18 knots, or in the supertanker class, which includes ships of between 26,000 and 50,000 tons deadweight, and speeds in excess of sixteen knots. Many of these modern ships are built to transport a large variety of oil cargoes—some are able to load as many as twenty different grades of lubricating oils and specialty products on a single voyage. New petroleum products continually present problems which challenge management's ingenuity.

The technical problems of loading and discharging oil cargoes are also of compelling importance. Tankers generally are engaged in one of two distinct types of service, distinguished as "clean" or "dirty" (sometimes also called "dark oil trade"). Ships in the latter trade carry only crude oils or such heavy fuels as "bunker C." This is the less complicated service, since handling such cargoes requires fewer shipboard activities than necessitated for refined products. Many of the heavier grades require that the oil be heated (to reduce its viscosity) before discharge is practicable. At least one grade of Venezuela crude oil must be thinned down with a light oil before it can be drained completely from the carrier's tanks.

The "clean" trade, on the other hand, requires elaborate preliminary preparations aboard ship, as, for instance, in the case of lubricating oil. Cargo tanks must be perfectly clean and wiped dry by hand to eliminate the slightest moisture, for even the smallest amount of water can render lubrication oil unsatisfactory on test. Tanks always are loaded flush with the deck to prevent condensation within the tank during the sea passage. Discharging must be carried out with proper appreciation of the characteristics of each type of cargo; lighter oils are pumped out first, so that there will be no contamination of color.

Safety is another managerial responsibility that is of paramount importance. On the oceans in the approaches to ports, at berth in port, handling cargo, and throughout the normal routine of maintenance work aboard ship, management must see that every precaution is taken to prevent accident. Closely related to safety are the functions involved in the navigation of the vessel: the selection of routings, the use of pilots, and the choice of adequate berths. Of major significance today is the provision and supervision by competent personnel of the elaborate equipment required on board tankers for safe navigation and rapid communication with shore installations.

Victualling, storing, scheduling, and bunkering a fleet of tankers in world-wide service are other important aspects of management. It is interesting to recall that few tankers are employed in regular service between designated ports, and hence many do not return to their home ports more than once in a year. To provide adequate supplies of victuals and stores of good quality and to procure such at reasonable prices for several hundred ships in practically all major oil-handling harbors of the world is an operation of impressive size. The application of sound principles of bunkering to a worldwide fleet of tankers, so that there will be a minimum of transportation of fuel and the smallest possible resultant sacrifice of cargo tonnage, is itself a considerable problem. It is complicated by the facts of tramp-tanker operation—voyages of indefinite duration, deviations, reroutings on short notice, and the normal requirements of servicing.

Personnel administration in tanker operation is an aspect of management which is becoming of increasing concern. To recruit, train, assign, and supervise officers and unlicensed crews, and to arrange for their proper care in the matter of pay and allotments, mail service, vacations, and discipline, is a formidable undertaking, particularly when, as often happens, the ships of a tanker fleet are scattered throughout the world. The current trend toward granting tanker seamen more vacation (or relief) time has necessitated enlarging the personnel pool of a fleet and installing complex record systems to insure that every man receives equitable treatment in accordance with an orderly system of rotation. Some owners have placed their ships under Liberian registry but staffed them with Italian or German seamen. By the terms of such employment, the Italian crew is entitled to a month or more vacation in Italy each year; the Germans receive the same form of vacation in their homeland. Similar situations arise with regard to other nationalities, not excluding the American. It is neither feasible to tie up the ship for the time its crew is vacationing nor to substitute a whole new crew. Hence some program of rotation must be developed and followed as consistently as possible to insure efficient operation of the ships and contentment among the seamen. The increasing mechanical efficiency of the ships, which can now be turned around in a port in a matter of hours, has created a

special set of problems and, in order to meet them, management has had to develop qualities of imagination and vision in the handling of seagoing personnel.

The pattern of employment followed by the major American oil companies is becoming more and more generally accepted throughout the American tanker industry. Under this plan, tanker seamen work approximately three months continuously, and then are granted one month vacation at full pay. In exchange for this liberal arrangement, the crews perform all loading and discharging operations in port, and relief personnel are not provided to take over these duties while the ship is working cargo. Since this involves a somewhat confining routine of employment, management adheres rigidly to its side of the contractual obligation by providing replacements for crew members at stated times and places. Never is the entire complement of the ship changed, and never is the entire permanent crew of the ship aboard. It is not difficult to envision the burden of administration which such a personnel program imposes upon management.

Differing quite markedly from dry-cargo ship operating procedures is the dependence which tanker owners place on vessel accounts and statistical reports. Not only is it desirable to have the records of expenditures of each ship—wages, port dues, pilotage fees, tug hire, and the like—made available at the earliest practicable moment, but likewise the tanker owner must be furnished promptly with information on the length of time required to handle a given cargo, the reasons for any delays encountered, and the analyses of ship working time. The best management practices attempt to handle these papers rapidly in order to discover possible trends toward greater efficiency or to detect the premonitory signals of tendencies in the opposite direction. Supervision and financial control increase somewhat disproportionately with the enlargement of a fleet and the geographical extent of its coverage. Business statesmanship of a high order is required if the maximum economic benefits of owning a fleet of tankers are to inure to the oil company.

One of the explanations for the problems described above is found in a number of ships operated under a single management. Since tankers rarely operate with any regularity from a home port, the opportunity often becomes difficult, or almost impossible, for a shore-based and permanently located office management to maintain the highly desirable personal contact between owner and seamen. But if the size of the fleet were reduced or the responsibility of management made less extensive, many owners feel that they would be able to prevent the development of an impersonal attitude in the home office toward the ships, and vice versa. One step toward accomplishing this goal has been the formation of subsidiary companies which own a comparatively small number of ships and operate them in a somewhat restricted geographic area.

For example, the Standard Oil Company (New Jersey) owns, through the Esso Shipping Company, a fleet of American-flag tankers which transport petroleum in the coastwise service and between nearby Caribbean countries and the United States refineries. In addition, there are subsidiaries in England, Belgium, France, Denmark, and other countries which own and operate tankers under their respective national registeries, in various foreign trades. Although all of these ships fly the "Esso" house-flag, the responsibility of management is retained by the individual owning company. Major policy is set by the Standard Oil Company, but the operation of the ships is left to the managerial staffs of the subsidiaries. In addition, Esso Shipping Company uses a fleet of considerable dimensions composed of time-chartered vessels for which Esso has no operational responsibility beyond cargo loading and unloading, planning how to fuel the ship for a voyage, and drawing up sailing orders.

No matter how contracted or how extensive the range of managerial responsibility, a matter of great concern to all tanker owners is the reduction of idle time for the ships. Unavoidable delays resulting from weather are accepted for what they are; the worry is over deficiencies in pumping capabilities by shore installations, crude oils which must be heated to insure rapidity of flow in the pipes connecting ship and storage tanks, congestion of available berths, and similar problems. One major company has set standards which must be met by its ships, depending upon the type of petroleum carried. These standards are known to all concerned, and failure to meet them results in censure of both ship and shore supervisors. New methods of working ships while in port constantly are under study and are of the utmost importance when the cost of the ship per hour is multiplied by the number of vessels in ports all over the world.

TANKER OPERATION

The business of operating tankers reflects the nature of the demand for petroleum. Necessarily the ships must be adapted to carry most efficiently their liquid cargoes, and consequently few of them are able to participate in anything but a one-way trade. The volatile products such as gasoline and kerosene require that vessels be free of all contaminants, and hence vessels so employed in the "clean" trades are not switched casually to the transportation of the heavier and blacker oils. It takes a great deal of effort, money, and time to convert a "dirty" or "dark oil" tanker to "clean" condition, and hence there is litt'e or no opportunity to transport crude in one direction and gasoline in the other.

In a similar manner, the gradual change in recent years in the production pattern of the petroleum industry has affected the employment of tankers. Whereas in the early decades of this century it was customary to locate refineries at or near the oil fields, today refineries, by preference, are being placed close to the consuming areas. Tankers of the largest size are used increasingly to haul crude petroleum from oil fields to metropolitan centers, whence distribution

of the product is left to small ships. Specialized problems thus have arisen which were unknown a quarter-century ago.

Tanker operators are vitally concerned with the problem of reducing the time their ships must spend in port. They can avoid mechanical breakdowns through the institution of systematic preventive maintenance programs. They must allow a tanker a certain minimum number of hours in which to load and discharge. Improvement has been obtained in this direction through increasing the capacities of ship's pumps. For example, the average pumping capacity of the 1938 "standard" 12,000-ton tanker was about 200 tons per hour. The T-2 tanker of World War II days was designed with larger pumps, and was able to handle approximately 700 tons per hour. Present-day medium-sized tankers are built to pump about 1,500 tons an hour. The supertankers, especially those built since 1953, are capable of handling about 2,500 to 3,000 tons of oil per hour, depending upon the grade of cargo carried and the available shore facilities.

The greatest single cause of loss of time in port is the delay incurred in placing the tanker alongside its berth. As the number of ships increases, the possibilities of such delay multiply. "Bunching" and "slip" thus become major worries of the tanker operator. "Bunching" is the condition which arises when vessel schedules overlap, and ships which are programmed to arrive in an orderly sequence, and thus to use the existing facilities in turn, converge upon the port at the same time. The resulting congestion inevitably causes delays and confusion in port operation.

"Slip" is the accumulation of minor and unexpected troubles which afflict ships in loading, sailing over thousands of miles of ocean, and discharging cargo. "Slip" occasions bunching, late arrivals, delays in cargo working, and many other failures to maintain the established schedule, whether within or beyond the control of the owner. Despite a high degree of vessel maintenance, efficient personnel, careful management, and watching, cajoling, checking, praising, criticizing, and the best of intentions, vessels do not always keep the schedule, and thus present the operator with a substantial amount of "slip." The situation varies from port to port, company to company, cargo to cargo, season to season, and only constant attention by operating management will keep "slip" from becoming a very grave matter.

The magnitude of the operational problems encountered by tanker owners may be grasped when it is recalled that in 1952, the world's fleet of 2,500 crude-oil carriers travelled 1,028,177 million ton-miles and transported 325,106,000 tons of oil. There were 290 important trade routes fanning out from eighteen exporting areas to forty-three receiving areas. About 45 per cent of the tanker traffic was engaged in hauling oil from the Persian Gulf and Eastern Mediterranean oil-fields to all parts of Europe, on voyages which were nearly twice as long as the average haul for all routes of 3,163 miles. Finally, it is important to note that these tankers were required to spend almost half—46.3 per cent to be exact—of their time in ballast voyages. Stating it affirmatively, they were employed in hauling revenue cargoes 53.7 per cent of the time.

According to a study completed in the early part of 1956, tankers totalling approximately 15,000,000 tons deadweight were being built for delivery before or during 1960. This great fleet in part will replace aging and obsolete tonnage, but it also will augment the total number of tankers available to transport the petroleum required around the world. It is expected that oil production will continue to rise until 1975 by about four per cent per year, but by that date the length of tanker voyages will be almost double those of today. A noticeable improvement in the efficiency of the oil carriers is expected. On the basis of these anticipations, it is likely that the tanker fleet in 1975 will aggregate 78 million tons, as compared to the 1952 fleet of 39.5 million tons deadweight capacity.

Of the economic importance of tankers and of the world's dependence on these hard-working ships, there is no doubt. That the tanker owner will continue to meet difficult problems as he maneuvers his increasingly big, fast, and vital ships over nearly three hundred routings between all parts of the world, there is complete certainty. There is equal certainty that the tanker owner and operator will find continuously increasing need for his skill as a specialist and all his knowledge of shipping, for his is a dynamic and constantly-challenging activity.

IMPROVING GAS TURBINE PERFORMANCE

ACKNOWLEDGEMENT

This reprint consists of three articles published in "Engineering." Parts I and II, written by Dr. B. W. Martin, appeared in the 1 March 1957 edition, and Part III, authored by Dr. F. J. Bayley and Mr. N. Bell, appeared in the 8 March 1957 issue. All three authors are members of the Department of Mechanical and Marine Engineering, King's College, University of Durham.

I—THERMAL EFFICENCY AT HIGH TEMPERATURES

INTRODUCTION

In the last decade the scale of application of the gas turbine to the field of industrial power production has fallen far short of original expectations. This can be partly attributed to the fact that the performance of existing industrial layouts and designs is not competitive. In this article the approximate limits of present performance are estimated, following which is an analysis of the potentialities and limitations of selected cycles at operating temperatures which necessitate cooling. It appears from the analysis that the inherent simplicity of the gas turbine can be combined with substantial improvements in performance over a specified temperature range.

Among the assets possessed by the gas turbine may be included simplicity, flexibility of design, and a relatively high power-weight ratio. Yet in spite of these advantages, it has become increasingly evident in the last few years that the gas turbine will not have a significant place in the field of industrial power production unless its performance can be improved to such an extent that it is clearly superior in this respect to the older forms of prime mover. Particularly would this involve a fairly large increase in overall thermal efficiency, so as to decrease the running costs, but it would also be advantageous to raise the specific output and thus reduce the size of an installation for a given output, thereby helping to lessen the first costs. Provided the reliability of the gas turbine for long-life industrial purposes could also be established, the achievement of these objectives, without sacrifice of the advantages already enumerated, would help to ensure its more widespread use at sea and in power stations, and probably for locomotion by road and rail.

Present-day opinion inclines to the view that the most promising way of attaining the above objectives is through an increase in the highest cycle temperature. Brown (1954) has stated that, in practice, with present refractory materials, a gas turbine combustion chamber could withstand a maximum gas temperature of 3,500° F (1,930° C). But the extreme working temperature of the alloys used in long-life gas turbines is no more than 1,500° F (820° C) and even this is true of materials only available on a laboratory scale. Furthermore, it is unlikely that metallurgical advances will lead to any sudden and large increase in this order of temperature. The implication is, therefore, that no real improvements in performance can be expected, unless the components of the prime mover which are exposed to the highest gas temperatures can be effectively cooled to, or otherwise maintained at, working temperatures in the range 1,200° to 1,400° F (650° to 760° C).

Cooling problems in the ducting and stationary components of the turbine, which are comparatively lightly stressed, can usually be fairly readily solved. One method is to provide such components with refractory lining, or to build them wholly of ceramic. This has been done in the case of the Pametrada experimental high-temperature gas turbine. There are a number of possible ways in which the metal of the heavily-loaded rotor blades and drum might be maintained at a satisfactory temperature level. These include the application, where necessary, of ceramic coatings, while there are two well known methods of utilizing the cooling properties of part of the air leaving the compressor. For the highest turbine inlet temperatures, where it is contended that air cooling

would be inadequate, there are several promising alternatives in which liquids are involved. But whichever method or combination of methods is adopted, the heat transferred by convection and radiation from the hot gas represents a loss of highly available thermal energy. This cooling loss has an adverse effect on the performance of the gas turbine, though the effect may be mitigated by transferring the energy to some auxiliary cycle capable of developing further power.

SCOPE OF ANALYSIS

The purpose of this article is first to assess the full-load performance of a fairly complex but uncooled type of gas-turbine cycle, which might reasonably be said to represent the approximate limit of practical possibility, having regard to manufacturing costs. Since the cycle is uncooled, the maximum cycle temperature is restricted to 1,430° F (777° C), with a suitable pressure ratio. If the performance of this cycle may be regarded as the best attainable in practice without cooling, it can be used as a standard of reference against which other cycles employing cooling may be compared. Thus the consequent improvement (if any) in performance can be assessed. The author believes that the conception of a high-temperature gas turbine is justified on several scores, not least of which is the opportunity it provides to reverse as far as possible the trend towards complexity of layout. One of the most important assets of the gas turbine would thus be retained. For this reason the full-load performance is examined of only the simplest cooled cycles. Allowance is made for cooling loss, but in order to obtain a fair comparison, operating conditions are otherwise identical with those of the uncooled but more complex cycles.

DESIGN ASSUMPTIONS

Overall pressure ratio, 15 to 1; compressor isentropic efficiency, 85 per cent, turbine isentropic efficiency, 85 per cent; heat-exchanger thermal ratio, 70 per cent; specific heat of air during compression, 0.24; isentropic index of air during compression, 1.40. The physical properties of air at elevated temperatures have been obtained from the *Gas Tables* of Keenan and Kaye.

PERFORMANCE OF UNCOOLED CYCLE

The uncooled double-compound cycle selected for examination is shown in Fig. 1, while Fig. 2 is the corresponding temperature-entropy diagram. The high-pressure turbine drives the high-pressure compressor, and the low-pressure turbine drives the low-pressure compressor. The uncoupled power turbine is in the gas circuit between the two compressor turbines and the performance of the basic cycle is improved as far as possible by the inclusion of an intercooler and heat exchanger, with reheat to the maximum cycle temperature of 1,430° F (777° C) before the power turbine and the low-pressure turbine. It is assumed that the total work of compression is shared equally between the compressors. The performance of this cycle over the whole load range but for slightly different conditions has been examined in detail by the author (1948) and discussed by Mallinson and Lewis (1948). It has been found to have satisfactory characteristics for marine installations, and where a heat exchanger is included the full-load

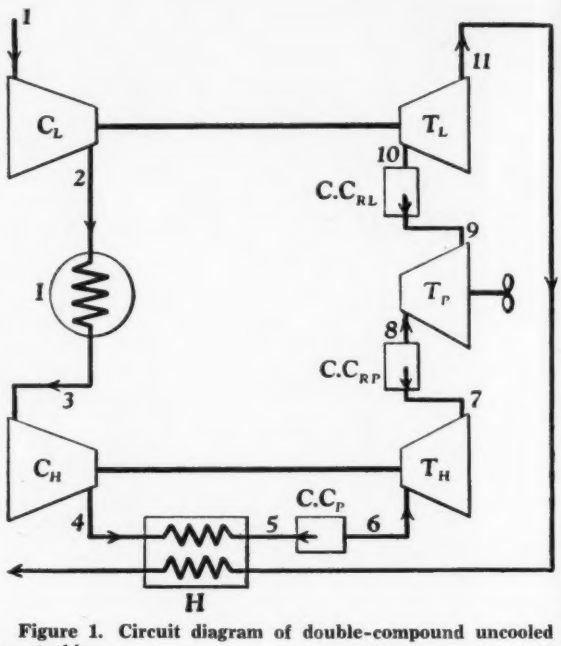


Figure 1. Circuit diagram of double-compound uncooled gas turbine.

C_L	low-pressure compressor.	T_H	high-pressure turbine.
I	intercooler.	CC_{RP}	first reheat chamber.
C_H	high-pressure compressor.	T_P	power turbine.
H	heat exchanger.	CC_{RL}	second reheat chamber.
CC_P	primary combustion chamber.	T_L	low-pressure turbine.

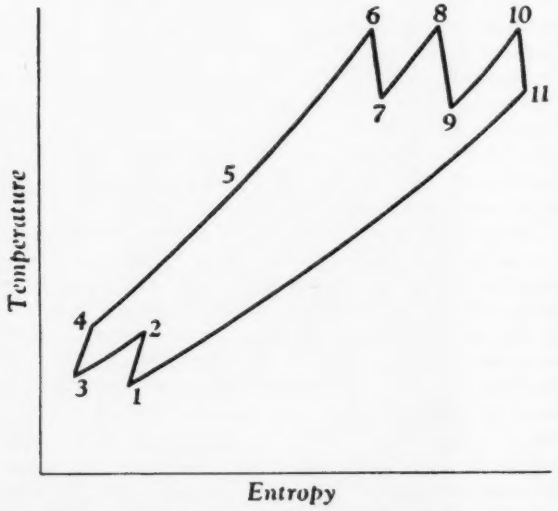


Figure 2. Temperature-entropy diagram for uncooled gas-turbine cycle.

thermal efficiency is maintained down to half-load. In a further discussion of the cycle, Brown points out that the low-pressure compressor-turbine combination can be regarded as a supercharger which can be put out of action during part-load running. The cycle is chosen as being among the most complex layouts which have yet been seriously considered for practical use.

The author's previous examination of the full-load performance of the cycle, based on the same maximum temperature but assuming rather better component efficiencies and an overall pressure ratio of 12 to 1, gave a thermal efficiency of 34.2 per cent and a specific output of 159 b.h.p. per lb. of air per second. This included allowances for pressure losses in the system, incomplete intercooling and mechanical transmission losses. Making similar allowances in the present case, the full-load performance is estimated as 33.6 per cent thermal efficiency (specific consumption 0.4 lb. per b.h.p. per hour) and about the same specific output as before. These data will, therefore, be used as a standard of comparison in what is to follow.

PERFORMANCE OF COOLED CYCLES

Figs. 3 and 4 show, respectively, the circuit diagram and the temperature-entropy diagram for one of the two cooled cycles to be examined. The other cycle differs from the one shown in Fig. 3 in one respect only; it does not include a heat exchanger. Its part-load performance has been assessed by Mallinson and Lewis and, for a maximum temperature of 1,430° F (777° C), appears satisfactory. Apart from the simplification brought about by using only one compressor-turbine combination, the cycle uses neither reheat nor intercooling. It is contended that since these modifications increase the specific output rather than, and sometimes at the expense of, the thermal efficiency, it is desirable that they be excluded from the cooled high-temperature cycle, by which it is intended to improve the performance as a whole. The overall pressure ratio is retained at 15 to 1 not only

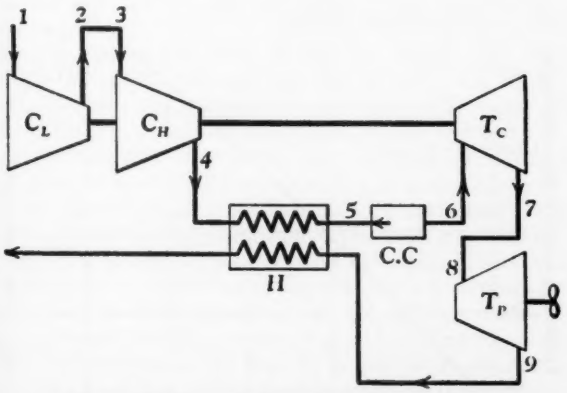


Figure 3. Diagram of cooled gas-turbine circuit.

C_L low-pressure compressor. CC combustion chamber.
C_H high-pressure compressor. T_C compressor turbine.
H heat exchanger. T_P power turbine.

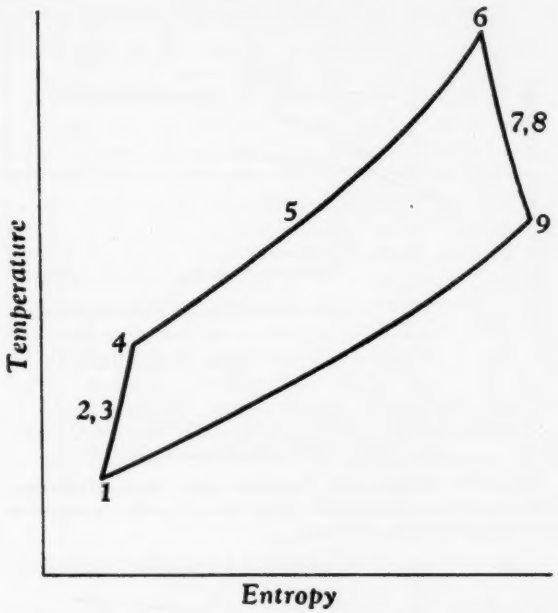


Figure 4. Temperature-entropy diagram for cooled gas-turbine cycle.

for comparative purposes, but also because an appreciable increase, while perhaps slightly improving the performance, would in practice tend to reduce the margin of advantage which the gas turbine has in respect to requisite strength of pipes and joints over the high-temperature high-pressure steam plant. A large increase in pressure ratio would also involve a rather more complex compression process.

The effect of reducing the compression ratio is, however, to bring about an increase in cooling-loss factor, which is defined by Brown (1950) as the ratio of heat loss to work done in a given turbine stage. The cooling loss factor is also an increasing function of maximum cycle temperature, and, in view of the limiting gas temperature which it has been suggested a combustion chamber could withstand, the present analysis covers the range between 1,400° F to 3,500° F (760° and 1,930° C); it is assumed that over this range the cooling loss factor increases in the manner portrayed by Brown from 6 to 30 per cent. This represents a slightly more conservative view of the heat loss than might be suggested from a double extrapolation of Brown's estimates, especially at the higher temperatures. This assessment arises from the author's lower evaluation of the probable convective loss to the blades (1955), which is based on Ainley's investigation (1953) of an air-cooled turbine. But, of course, any estimate of cooling loss temperature variation depends very much on turbine design and must at the present time be regarded as tentative.

Fig. 5 shows the variation of estimated thermal efficiency of the two cycles assuming that the thermal energy extracted by cooling is wasted; Fig. 6 shows the overall effect of using this energy in an auxiliary

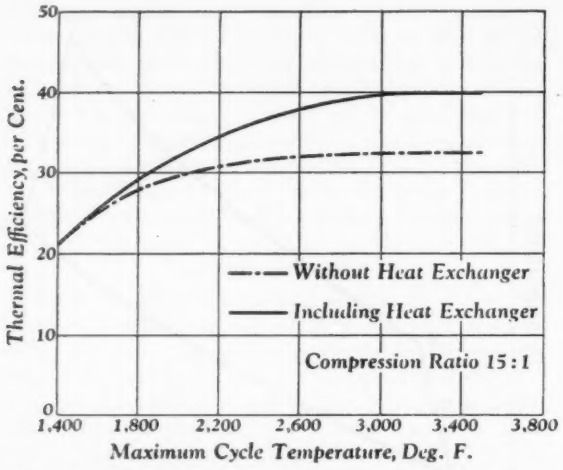


Figure 5. Relationship between cycle thermal efficiency and maximum temperature when thermal energy is extracted by cooling and goes to waste.

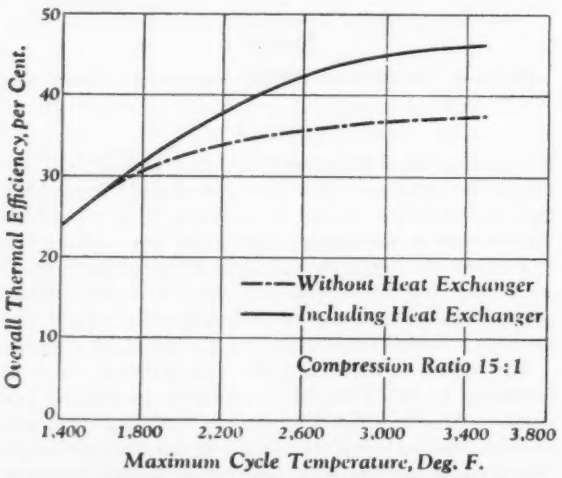


Figure 6. Improved overall efficiency due to utilization of extracted thermal energy in auxiliary cycle, with an assumed efficiency of 30 per cent.

cycle which is assumed to have an efficiency of 30 per cent. Fig. 7 illustrates the effect of maximum temperature on specific output for both cooled cycles, the small change in output due to inclusion of a heat exchanger being neglected. Allowance is, however, made for pressure losses in the other components and ducting, and for transmission loss.

It emerges from Figs. 5 and 6 that, given realistic data, a heat exchanger is essential if there is to be any substantial improvement in thermal efficiency; in fact the cycle without a heat exchanger in which the heat extracted by cooling is thrown away, actually has a lower thermal efficiency than that of Fig. 1 over the whole temperature range considered. Furthermore, it is only just possible to achieve 40 per cent thermal efficiency *with* a heat exchanger where the energy from cooling is wasted. But, given an

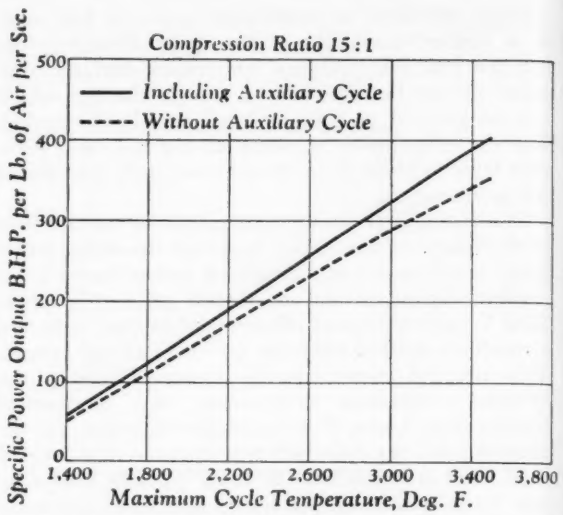


Figure 7. Variation of specific output with maximum cycle temperature for both cooled cycles.

auxiliary power cycle, there is no doubt of the improvement in overall efficiency, which exceeds 45 per cent (specific consumption 0.30 lb. per b.h.p. hour) at the highest temperatures. The efficiency of the same cycle (shown in Fig. 3), assuming no cooling, ranges from 36.3 per cent at 2,000° F (1,093° C) to 50.7 per cent at 3,500° F (1,927° C).

The shape of the four curves suggests, however, that there is no commensurate gain by exceeding 3,000° F (1,650° C) even if this should be possible; moreover, there is some danger that unless large compression ratios are used the turbine exhaust temperature would be so high that further cooling would be needed before the hot gases could be passed through a heat exchanger without ultimate damage to the latter. This is shown in Fig. 8, where turbine exhaust temperature is plotted against maximum

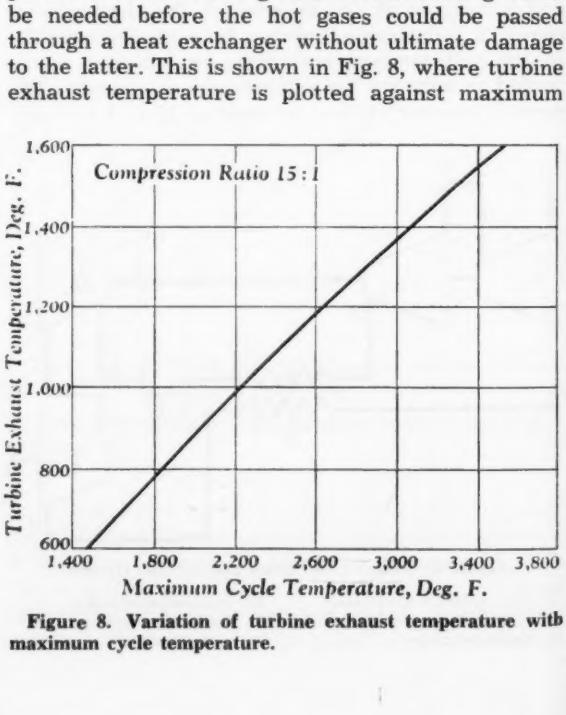


Figure 8. Variation of turbine exhaust temperature with maximum cycle temperature.

cycle temperature. Such further cooling, even if utilized in the auxiliary cycle, would reduce the thermal efficiencies shown in Fig. 5 and 6, and would probably lead to a definite maximum in the region of 3,000° F (1,650° C), thus strengthening the argument against exceeding this temperature.

The relationship between specific output and maximum cycle temperature is seen to be roughly linear (Fig. 7). The specific output is the same as for the uncooled cycle (159 b.h.p. per lb. of air per second) at a temperature between 2,000° F (1,093° C) and 2,100° F (1,149° C), while at 3,000° F (1,650° C) there is a gain of over 100 per cent if an auxiliary cycle is used. This significant improvement means that much could be done to reduce the size of the components used in developing a given power.

CONCLUDING REMARKS

If the underlying theme of the present article is correct, that development of the high-temperature gas turbine should be coupled with the use of the simplest possible operating cycles, the conclusion then seems inescapable that no perceptible improvement in present-day performance can be expected for maximum temperatures below 2,000° F (1,093° C). Furthermore, for the gains to be really worth while, the aim should be to operate successfully at temperatures in the range 2,500° F (1,370° C) to 3,000° F (1,650° C), preferably with a bias towards the latter figure. If cooling losses at the highest temperatures have been underestimated, which may well be the case, the true relationship between thermal efficiency and maximum temperature should tend towards a peak value, probably at around 3,000° F (1,650° C). All the indications are, therefore, that there is nothing to be gained and perhaps something to be lost, by exceeding this temperature, for even if cooling losses have been overestimated (rather than the reverse), the improvement in thermal efficiency with temperature in this region is likely to be minute.

II—THE EFFECT OF INTERCOOLING ON EFFICIENCY

INTRODUCTION

This article seeks to establish, in quantitative terms, the conditions under which the thermal efficiency of the simple gas turbine is improved, reduced, or remains unchanged by the addition of intercooling to the cycle. The investigation (which takes account of component efficiencies and variation of specific heats with temperature) shows, among other things, that above a certain maximum temperature the plain cycle has a better efficiency than the equivalent intercooled cycle, but that at the highest maximum temperatures the performance of the two arrangements does not differ appreciably.

The fundamentals of gas turbine technology are now so widely known, due to the works of such authors as Thomson (1948), Cohen and Rogers (1951), Hodge (1955), Roxbee Cox (1955) and others, that the main reasons for the changes in performance due to the addition of heat exchange, reheat, and intercooling to the simple cycle are generally appreciated. Heat exchange improves the thermal efficiency of the cycle but not the power output per pound of air, while reheat raises the output but simultaneously reduces the efficiency. Heat exchange and reheat together increase both output and efficiency, and this is true also of heat exchange with intercooling, or a combination of all three of these modifications. An interesting case which does not appear to have received any special attention is that of intercooling by itself. While the net output is raised due to the reduction in total compression work, intercooling has the additional effect of lowering the final compression temperature, and thus of increasing the heat to be added in the combustion chamber. It therefore depends on the relative magnitude of the two increases whether the thermal efficiency is raised or lowered, or remains unchanged.

It is the object of this article to ascertain the conditions which govern these changes, and to determine their order of magnitude for operating conditions likely to be encountered in practice. Some idealization is necessary to reduce the problem to reasonable proportions, and so it is assumed that when intercooling is considered, the isentropic efficiency and work input of each of the two compressor stages is the same. The treatment has not been extended to cover the case of multiple intercooling with more than two compression stages, as this is considered to be almost outside the range of practical possibility unless very large pressure ratios are contemplated. It is also assumed that cooling to the initial air temperature is complete, and that there is no pressure loss in the intercooler, in the combustion chamber, or in any of the ducting between components. The combustion and mechanical transmission efficiencies are taken to be 100 per cent. Fortunately these approximations introduce only minor departures from the values likely to be obtained in practice. The effect of change of specific heat with temperature is considered at a later stage in the text, after the primary governing conditions have been deduced.

Notation

T absolute temperature.	η_c compressor isentropic efficiency.
t cycle overall temperature ratio.	η_T turbine isentropic efficiency.
R cycle pressure ratio.	η cycle thermal efficiency.
γ ratio of specific heats.	W cycle net work output per lb. of air
C_p specific heat at constant pressure.	Q heat input per lb.of air

Suffixes "p" and "i" refer to the plain and intercooled cycles respectively.

ANALYSIS OF PLAIN CYCLE

The gas circuit and temperature-entropy diagram

for the plain cycle are shown in Fig. 9. The net output per lb. of air is given by

$$W = C_p(T_3 - T_4) - C_p(T_2 - T_1)$$
$$= C_p\left[\eta_T T_3\left(1 - R^{\frac{1-\gamma}{\gamma}}\right) - \frac{T_1}{\eta_c}\left(R^{\frac{\gamma-1}{\gamma}} - 1\right)\right] \quad \ldots\ldots\ldots\ldots\ldots (1)$$

while the heat input per lb. is

$$Q = C_p(T_3 - T_2)$$
$$= C_p\left[T_3 - T_1 - \frac{T_1}{\eta_c}\left(R^{\frac{\gamma-1}{\gamma}} - 1\right)\right].$$

The cycle thermal efficiency is then represented by

$$\eta_p = \frac{W}{Q} = \frac{\eta_T T_3\left(1 - R^{\frac{1-\gamma}{\gamma}}\right) - \frac{T_1}{\eta_c}\left(R^{\frac{\gamma-1}{\gamma}} - 1\right)}{T_3 - T_1 - \frac{T_1}{\eta_c}\left(R^{\frac{\gamma-1}{\gamma}} - 1\right)} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Figure 9. Circuit diagram and temperature-entropy diagram for plain gas-turbine cycle.

C compressor. CC combustion chamber. T turbine.

ANALYSIS OF INTERCOOLED CYCLE

The arrangement of components for the intercooled cycle is shown in Fig. 10 (*a*), and the corresponding temperature-entropy diagram in Fig. 10 (*b*). Since the condition for minimum total compression work is assumed in a cycle where the pressure ratio is R, the pressure ratio in each compression stage is $R^{\frac{1}{2}}$. It should also be noted that $T_5 = T_1$ and $T_6 = T_2$. The net output of work per lb. of air is then

$$W = C_p(T_3 - T_4) - 2C_p(T_2 - T_1)$$
$$= C_p\left[\eta_T T_3\left(1 - R^{\frac{1-\gamma}{\gamma}}\right) - \frac{2T_1}{\eta_c}\left(R^{\frac{\gamma-1}{2\gamma}} - 1\right)\right]. \quad \ldots\ldots\ldots\ldots\ldots (3)$$

The heat input per lb. is

$$Q = C_p(T_3 - T_6)$$
$$= C_p\left[T_3 - T_1 - \frac{T_1}{\eta_c}\left(R^{\frac{\gamma-1}{\gamma}} - 1\right)\right].$$

As before, the thermal efficiency is given by

$$\eta_i = \frac{W}{Q} = \frac{\eta_T T_3\left(1 - R^{\frac{1-\gamma}{\gamma}}\right) - \frac{2T_1}{\eta_c}\left(R^{\frac{\gamma-1}{2\gamma}} - 1\right)}{T_3 - T_1 - \frac{T_1}{\eta_c}\left(R^{\frac{\gamma-1}{2\gamma}} - \right)1} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

CONDITIONS GOVERNING CYCLE EFFICIENCY CHANGES

It is convenient to write $K = R^{\frac{\gamma-1}{\gamma}}$, and to make the following substitutions.

Let

$$A = \eta_T T_3\left(1 - \frac{1}{K}\right), B = \frac{2T_1}{\eta_c}\left(K^{\frac{1}{2}} - 1\right)$$

and

$$C = (T_3 - T_1), D = \frac{T_1}{\eta_c}(K - 1).$$

Then $B\left(K^{\frac{1}{2}} + 1\right) = 2D$.

Reference to equations (2) and (4) shows that the plain cycle will then have the greater thermal efficiency if

$$\frac{A - D}{C - D} > \frac{A - 2D/(K^{\frac{1}{2}} + 1)}{C - D\ /(K^{\frac{1}{2}} + 1)} \quad \ldots\ldots\ldots (5)$$

This inequality can be reduced to

$$AK^{\frac{1}{2}} + C(1 - K^{\frac{1}{2}}) > D \quad \ldots\ldots\ldots (6)$$

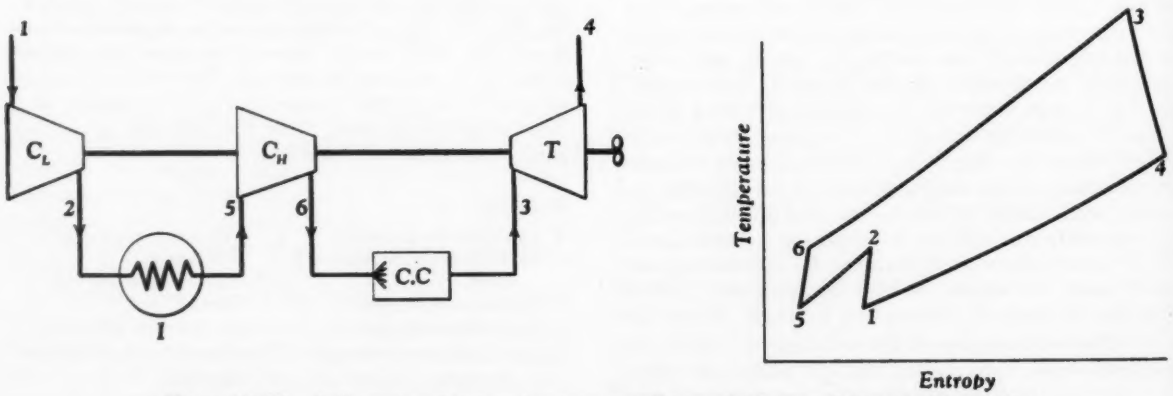


Figure 10. Circuit diagram and temperature-entropy diagram for intercooled gas-turbine cycle.

C_L low-pressure compressor.
CC combustion chamber.
C_H high-pressure compressor.
T turbine.
I intercooler.

Resubstitution for A, C and D leads ultimately to the condition that the cycle overall temperature ratio $t = \frac{T_3}{T_1}$ must satisfy the inequality

$$t > \frac{K + K^{\frac{1}{2}}(1 - \eta_c)}{\eta_c [\eta_T - K^{\frac{1}{2}}(1 - \eta_T)]} \quad \ldots\ldots\ldots (7)$$

This can be interpreted as meaning that for fixed component efficiencies and a given pressure ratio, the plain cycle will be the more efficient if the maximum cycle temperature exceeds a particular value, determined from (7). This, of course, assumes that the minimum cycle temperature is constant; it will be taken as 288° K in what follows. In Fig. 11 the maximum cycle temperature thus determined is seen to increase when plotted against pressure ratio for different values of compressor efficiency and turbine efficiency. That these last two parameters do not exert equal influence is shown by the curves representing the three conditions (*a*) $\eta_c = \eta_T = 0.85$, (*b*) $\eta_c = 0.9$, $\eta_T = 0.8$, (*c*) $\eta_c = 0.8$, $\eta_T = 0.9$, which, had this been the case, might have been expected to be coincident.

The figure confirms what is already well known, namely that intercooling is more likely to have a beneficial effect on the thermal efficiency of a cycle with low component efficiencies than on one where the component efficiencies are high. Because the two efficiencies do not exert the same influence, any benefit to the cycle efficiency will be greater with a low turbine efficiency than with the same value of compressor efficiency. It is, in fact, obvious from (7) that when the turbine efficiency falls to such a value that

$$\eta_T = \frac{K^{\frac{1}{2}}}{K^{\frac{1}{2}} + 1} \quad \ldots\ldots\ldots (8)$$

the value of t, and hence of T_3 (at which the plain cycle attains a superior efficiency) becomes infinitely large. Thus the intercooled cycle is then always the more efficient, irrespective of the compressor efficiency.

Equation (8) is plotted in Fig. 12, from which the flat nature of the curve makes it clear that this limiting condition corresponds to a turbine efficiency of

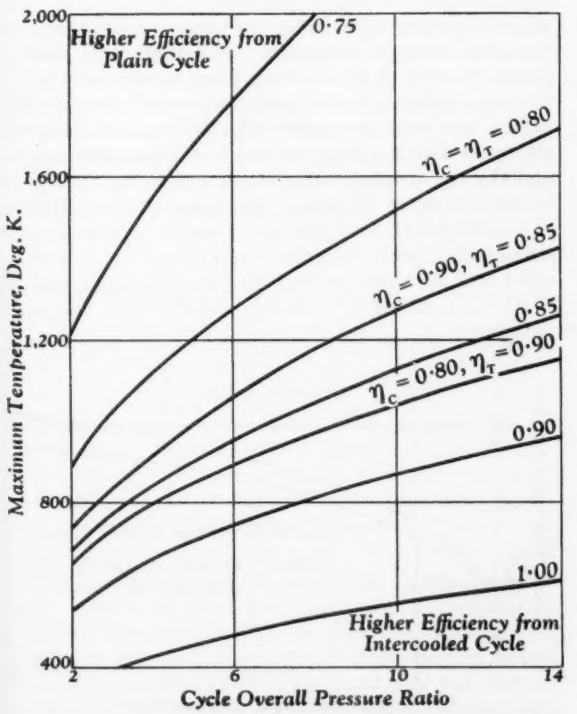


Figure 11. Conditions for increased thermal efficiency for various values of component isentropic efficiency (max. cycle temp. and pressure ratio).

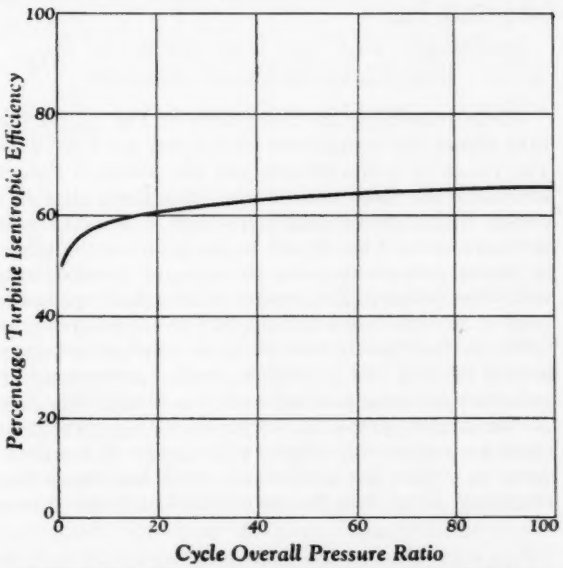


Figure 12. Values of turbine efficiency below which the intercooled cycle is always the more efficient.

the order of 60 per cent over a wide range of pressure ratios from about 9 to 30. (Inspection of (7) shows that there is no such limiting condition in the case of the compressor efficiency.) While the turbine efficiency quoted is much lower than would normally be tolerated in a practical case, it is still perfectly possible for both plain and intercooled cycles to produce positive work. Fig. 11 also confirms that for given component efficiencies and a fixed maximum cycle temperature an increase in pressure ratio will increase the likelihood of the intercooled cycle being the more efficient, if it does not actually make it so.

The above analysis is incomplete, because there are additional limitations imposed by the fact that the cycles must produce positive work. This condition is given by equation (1) for the plain cycle, which can be expressed as

$$t > \frac{K}{\eta_c \eta_T} \quad \ldots\ldots\ldots (9)$$

For the intercooled cycle equation (3) yields

$$t > \frac{2}{\eta_c \eta_T} \frac{K}{(K^{1/2} + 1)} \quad \ldots\ldots\ldots (10)$$

It may be readily shown that

$$\frac{K}{\eta_c \eta_T} > \frac{K}{\eta_c \eta_T} \frac{2}{(K^{1/2} + 1)} \quad \ldots\ldots\ldots (11)$$

and, in addition, for positive values of K and for values of η_c and η_T less than unity, it can be shown that the right hand side of (7)

$$\frac{K + K^{1/2}(1 - \eta_c)}{\eta_c [\eta_T - K^{1/2}(1 - \eta_T)]} > \frac{K}{\eta_c \eta_T} > \frac{K}{\eta_c \eta_T} \frac{2}{(K^{1/2} + 1)} \quad (12)$$

from (11). We therefore conclude that the plain cycle has the better efficiency when (7) holds good, but that the intercooled cycle is best in the restricted range such that

$$\frac{K + K^{1/2}(1 - \eta_c)}{\eta_c [\eta_T - K^{1/2}(1 - \eta_T)]} > t > \frac{2}{\eta_c \eta_T} \frac{K}{(K^{1/2} + 1)} \quad \ldots (13)$$

These conditions are illustrated in Fig. 13 for the case where the component efficiencies are each 0.85. The range of temperatures and the absolute values for which the intercooled cycle yields the higher efficiency with positive output are seen to increase with pressure ratio. Also shown in the graph is the effect of taking into account the variation of specific heats with temperature. The generally accepted method is used of substituting a mean value of 0.274 in place of 0.240 for the specific heat of air at constant pressure during heating and expansion, with a corresponding reduction in isentropic index from 1.40 to 1.333. Only at the higher pressure ratios does this correction exert an appreciable effect on the range of temperatures in which the intercooled cycle has the better efficiency. Even then the lower absolute level of temperature (the condition for positive work) is virtually unchanged. At a pressure ratio of 16, the upper temperature above which the plain cycle is superior, can now be more accurately determined as 1,310° K, compared with 1,130° K when specific heat variation is ignored. The discrepancy is, however, less than 100° C for pressure ratios below about 10.

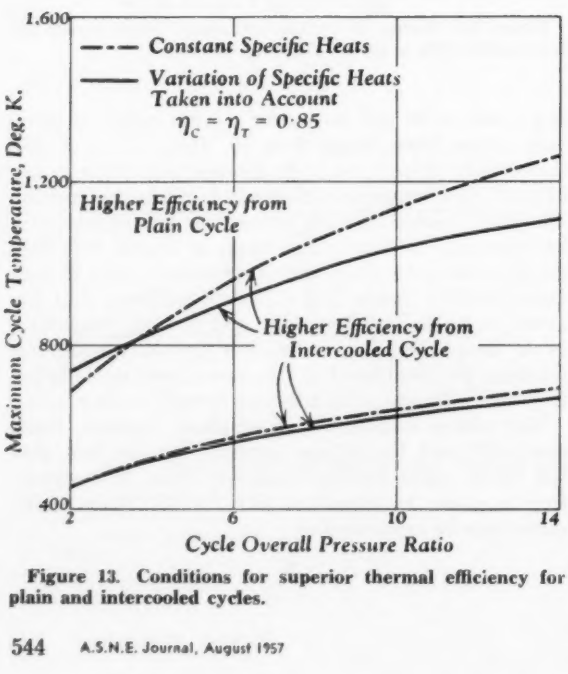


Figure 13. Conditions for superior thermal efficiency for plain and intercooled cycles.

Reverting to Fig. 11, it should be noted that in the special case of ideal component performance, such that $\eta_c = \eta_T = 1.0$, inequalities (7) and (9) both reduce to

$$t > K, \quad \text{i.e.,} \quad \frac{T_3}{T_1} > R^{\frac{\gamma-1}{\gamma}} = \frac{T_2}{T_1} \text{ or } \quad T_3 > T_2$$

This implies that the condition for superiority of the plain cycle does not hold good in the hypothetical limiting case when no heat is supplied.

CYCLE EFFICIENCIES

It is desirable first to obtain an expression corresponding to equality of efficiency between the plain and intercooled cycles. This may easily be done by substituting the equation resulting from (7)

$$\frac{T_3}{T_1} = \frac{K + K^{1/2}(1 - \eta_c)}{\eta_c [\eta_T - K^{1/2}(1 - \eta_T)]}$$

into (2) or (4). After some simplification we find that

$$\eta = 1 - K^{-1/2} = 1 - \frac{1}{R^{\frac{\gamma-1}{2\gamma}}} \quad \ldots\ldots\ldots (14)$$

which happens also to be the thermal efficiency of the ideal constant-pressure or Joule cycle with a pressure ratio of $R^{1/2}$. A surprising feature of (14) is that it is independent of both the overall temperature ratio t and the component efficiencies η_c and η_T, the efficiency being a function only of the pressure ratio and the isentropic index. The lower curve in Fig. 14 shows the effect of taking into account the variation of specific heats. At a pressure ratio of 10, the thermal efficiency of both cycles is about 28 per cent for constant specific heats, which must be compared with 25

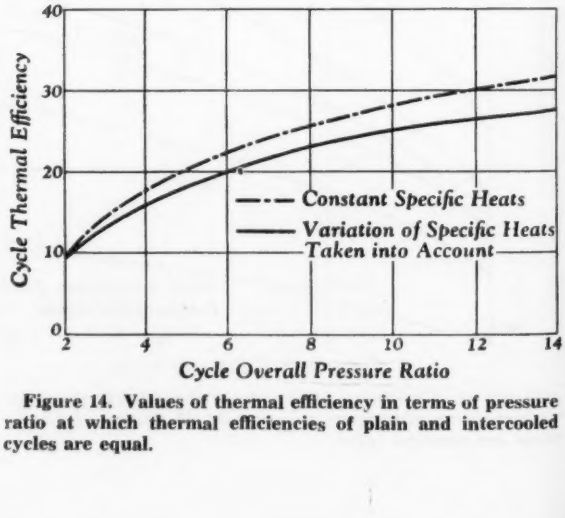


Figure 14. Values of thermal efficiency in terms of pressure ratio at which thermal efficiencies of plain and intercooled cycles are equal.

per cent when the correction for specific heats is applied.

The order of percentage change in thermal efficiency due to using the intercooled cycle in place of the plain cycle is best illustrated by a representative example, in which the overall pressure ratio is 14, the compressor efficiency being 0.85 and the turbine efficiency 0.90. The change in efficiency is investigated for a range of temperatures from 850° K to 2,200° K. The intercooled cycle does not produce positive work for maximum temperatures below about 620° K, while the plain cycle requires 770° K for positive output. Variation of specific heats is taken into account. The results are presented in graphical form in Fig. 15, from which it is clear that in the narrow range of temperatures between 770° K and 920° K the intercooled cycle has the better efficiency. The slope of the curve representing percentage efficiency change is very steep in this narrow temperature range, the gain falling from 20 per cent at 850° K to 5 per cent at 890° K.

Between 920° K where the efficiencies are equal at 27 per cent and about 1,200° K the percentage improvement in efficiency with the *plain* cycle rises steadily to a maximum of nearly 7 per cent but at higher temperatures tends to fall almost linearly to about 4 per cent at 2,200° K. Comparative values of efficiency at this temperature are, for the plain cycle 40.6 per cent, and for the intercooled cycle, 39.0 per cent. Over a very wide range of temperatures the plain cycle therefore has clearly the better efficiency.

Fig. 15 also shows the percentage gain in power output from the intercooled cycle. With increasing maximum temperature the gain falls rapidly from over 100 per cent at 920° K to only 10 per cent at 2,200° K. Thus ultimately there is little to choose between the performance of the two cycles, and this is seen to be true in the general case as T_3 becomes very large by, comparison of (1) with (3), and (2)

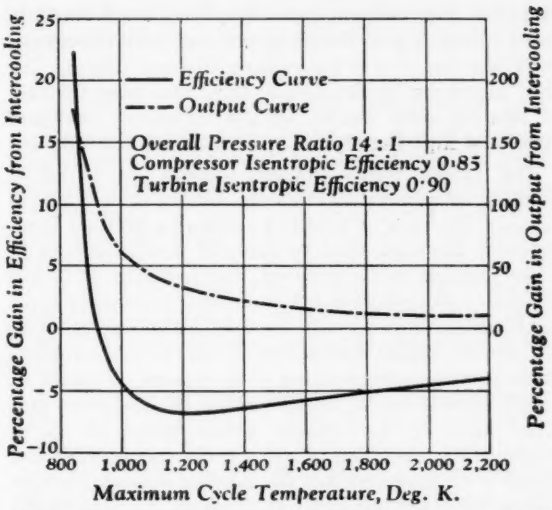


Figure 15. Changes in efficiency and output as a result of intercooling.

with (4). The efficiency of the intercooled cycle could be raised above that of the plain cycle by the inclusion of a heat exchanger. But if the main purpose of high-temperature operation is the improvement of efficiency rather than output, this can be achieved by a heat exchanger alone. Increased specific output is, of course, also obtained by raising the maximum temperature of any operating cycle; in Part I it is estimated that in a relatively simple arrangement of compressors, combustion chamber and turbines, involving only a heat exchanger, the output could be increased from 150 to more than 300 b.h.p. per lb. of air per second by raising the maximum temperature from 1,400° K to 2,000° K. Such considerations would seem to rule out the use of intercooled cycles at the highest operating temperatures.

III—HEAT TRANSFER CHARACTERISTICS OF A LIQUID METAL IN THE CLOSED THERMOSYPHON

INTRODUCTION

This paper presents an account of an experimental investigation concerning the operation of the thermosyphon system of heat transfer; mercury was used as the internal coolant. Quantities of this liquid metal were enclosed in the hollow spokes of a wheel rotated at speeds up to 1,500 r.p.m.; the inner halves of the wheel passed through a cold air stream and the outer halves through hot gas from a combustion chamber. The variation in the observed rates of heat transfer suggests that, owing to the restriction placed upon convective motion in the liquid by the narrow confines of the thermosyphon elements, the only significant transfer of heat between the hot and cold sides resulted from evaporation and condensation. Further and more important, it was found that under the conditions of this experimental investigation the returning stream of condensate from the cooled ends of the thermosyphon elements contributed significantly to the heat transfer process.

It is now becoming generally accepted that a worthwhile improvement in the performance of internal combustion turbines will only be possible by increasing the maximum gas temperature to such a level as to make inevitable liquid cooling of the turbine rotor blades. Air, the logical coolant for gas turbines, because of its low thermal capacity and conductivity allows only a limited increase in maximum temperature beyond that possible in uncooled engines, although air-cooling systems have the great advantage of requiring a minimum of mechanical complication.

It is for this reason, probably, that until recently most research and development has been concerned with the use of air for cooling turbine blading, for the "plumbing" difficulties, as they have been termed, of dealing with liquids in the inevitably confined spaces of high-speed turbine rotors are formidable.

The closed thermosyphon system, in which a quantity of coolant is enclosed within each blade to act as a conveyor of heat to a secondary coolant flowing over the root, enables some of the difficulties of liquid cooling to be avoided. For instance, it is not necessary to provide continuous flow passages within the blade section, as with forced-convection systems, nor are the blades themselves subjected to the hydrostatic forces corresponding to a column of liquid of height almost equal to the radius of the rotor and acted upon by centrifugal accelerations of up to 30,000 *g*. Further, and of great importance, since the liquid is enclosed within the cooling passages in the blades, these are not liable to blockage by centrifugal deposition of solid impurities in the main circulating coolant, a problem present with all open liquid-cooling systems.

Another great advantage of the closed thermosyphon is that it makes possible a wider choice of coolant, since liquids which by their toxic or chemically reactive nature are impracticable in open systems can be sealed into the blades and used in conjunction with a more conventional external coolant at the root. This is an important factor in turbine cooling applications of the thermosyphon because water, the obvious choice of liquid, while it has many advantages—namely high latent heat, good thermal conductivity, chemical inertness and abundance, among others—has the one great disadvantage that its critical temperature is only 704° F (373° C). This means that turbine blades in which water is used as the coolant must either operate at temperatures much less than the materials available will withstand, with the thermodynamic penalties which this undercooling implies, or, alternatively, the whole cooling system must be pressurized to at least 3,200 lb. per sq. in., and evaporative methods of heat transfer, with their many advantages, ruled out. Unfortunately, there are few liquids known which have critical temperatures higher than that of water and in practice, for purposes of turbine cooling, the only alternatives to water are the liquid metals, the properties of which are relatively unknown.

In this paper some experiments carried out in the Stephenson Engineering Laboratories of the University of Durham are briefly described, in which the heat transfer characteristics of liquid metals in the closed thermosyphon have been investigated. Although the results obtained are provisional and of a qualitative nature it is thought that the trends which they indicate are sufficiently unexpected to be of interest to others who are engaged in or are contemplating work of a similar nature in connection with the cooling of gas turbine blades or other problems for which liquid metals are particularly useful.

APPARATUS AND PROCEDURE

The apparatus used for the experiments described here was originally designed and operated by Dr. Henry Cohen, and is described in detail by Cohen and Bayley (1955). Briefly, the heat transferring apparatus (Fig. 16) consists of a wheel which can be rotated at speeds up to 2,000 r.p.m. and which has 24 hollow spokes in which the coolant to be tested can be placed. During part of each revolution and outer halves of the spokes pass through a stream of hot gas from a gas-turbine combustion chamber, while the inner halves similarly pass through a stream of air at about room temperature supplied from a blower which also delivers air to the combustion chamber. The rise in temperature of the air in passing through the apparatus is accurately measured and from its rate of flow the amount of heat transferred by the thermosyphon action of the liquid within the spokes or elements can be determined. No attempt was made to measure the temperatures of the rotating elements and accordingly the apparatus should be regarded as giving a qualitative or comparative picture of the different thermosyphon arrangements tested, rather than a detailed quantitative analysis of the heat-transfer processes occurring. For this latter purpose of far more elaborate and costly apparatus would be necessary.

For the tests described here, mercury, the most readily obtainable of the liquid metals and the one of which the physical properties are best known, has been used as the coolant. Amounts sufficient to fill one-quarter, one-half, three-quarters and the whole of the heated length were put into the hollow spokes with a graduated burette. Measurements of the rate of heat flow from the gas stream to the cold air have been made at speeds of 500, 1,000 and 1,500 r.p.m., corresponding to mean centrifugal accelerations in the heated ends of the thermosyphon of 49, 196 and 440 times the acceleration due to gravity. To obtain adequate rates of heat flow the gas temperature has been kept constant throughout the test series at 1,025° F (552° C), which is considerably above the

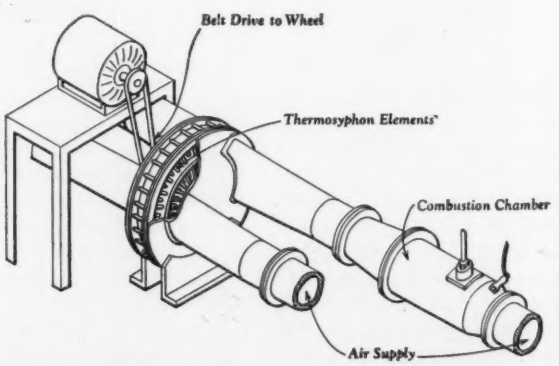


Figure 16. Experimental apparatus for determining the rate of heat transfer in a rotating thermosyphon. The spokes of the wheel correspond to the hollow blades of a gas turbine in which liquid metal is sealed.

temperature at which the apparatus was designed to operate. Consequently, considerable mechanical development has been necessary, mainly to overcome the problem of thermal distortion.

The procedure adopted for the tests has closely followed that developed by Cohen. Tests were first run to determine at each speed the rate of heat transfer by all means other than through the thermosyphon elements. Then followed, for comparative purposes, experiments to measure the rates of heat flow with empty elements, before the appropriate quantities of mercury were inserted for the main investigation to begin. Before and after each series of tests the thermosyphon elements were weighed to ensure that the required quantity of mercury had been put into the elements and to check that the sealing system had remained tight.

RESULTS

The rates of heat flow in B.T.U. per second through the 24 thermosyphon elements observed during the tests with the different quantities of mercury and at the three speeds are given in Table I.

TABLE I.—*Experimental results for heat flow in thermosyphon elements.*

Elements, 3/8 in. o.d., 1/4 in. bore, 2 3/4 in. heated length, 3 1/8 in. cooled length.

Filling quantity	Speed, r.p.m.	Net heat flow, B.T.U. per sec.
Empty	500	0.451
	1,000	0.485
	1,500	0.414
Heated end 1/4 full	500	0.504
	1,000	0.528
	1,500	0.461
Heated end 1/2 full	500	0.481
	1,000	0.409
	1,500	0.283
Heated end 3/4 full	500	0.450
	1,000	0.376
	1,500	0.254
Heated end full	500	0.531
	1,000	0.552
	1,500	0.428

At each speed it is seen that the insertion of the first small quantity of mercury caused the rate of heat flow from the heated to the cooled ends of the thermosyphon elements to increase, as would be expected, above the values observed with no internal coolant. At 500 r.p.m. increasing the quantity of mercury in the elements led to no substantial change in the rate of heat flow until the heated length was full. At the two higher speeds the strange result was obtained that the rates of heat flow fell with the addition of more coolant, to less than that observed with the empty elements, until the heated length was completely submerged.

MECHANISM OF HEAT TRANSFER PROCESS

These unexpected results which, it will be shown, are of great significance in the application of the thermosyphon to turbine cooling, can be explained by reference to the modes of heat transfer which can obtain in liquid-filled elements. In the tests described in this article the only means whereby heat could be transferred through the coolant to the cold ends was by evaporation and condensation of the mercury, or by metallic conduction along the tube walls.

It would be expected that most of the vapor would form at the free surface of the liquid, the latent heat being supplied by convective motion arising from buoyancy forces in the centrifugal acceleration field caused by rotation of the wheel. If, however, it is assumed that heat transfer takes place only by boiling in the liquid column, then, in view of the very high coefficients associated with this mode of heat transfer, the walls of each element would take up a temperature distribution following closely the saturation temperatures of the coolant at the prevailing hydrostatic pressures. Fig. 17 shows the variation in saturation temperature along the liquid column in the heated ends of each element for the quantities of mercury tested at the two speeds, 500 and 1,000 r.p.m. Similar, but steeper, lines are obtained for con-

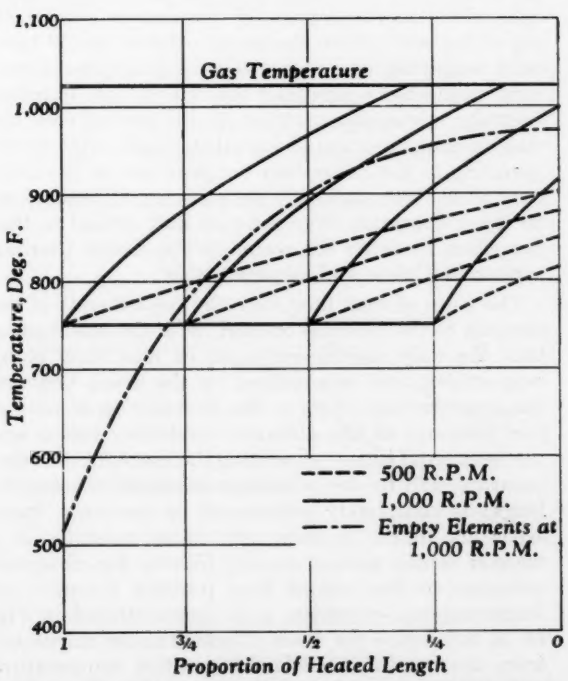


Figure 17. Saturation temperature distribution in rotating elements at two speeds—500 and 1,000 r.p.m. Cooling is effected by evaporation and condensation.

ditions at 1,500 r.p.m., but are not shown to avoid further confusing the figure. The pressure at each radius, r, due to the column of mercury was calculated from the expression $\int \frac{r}{r_s}\sigma\omega^2 r dr$, where r_s is the radius of the free liquid surface, ω the angular velocity of rotation and σ the density of mercury. The pressure above the surface would depend upon the largely unknown condition which prevailed at the cooled end of this completely enclosed system. If the mercury vapor diffused throughout the air enclosed in the elements, the additional partial pressure of this gas would have raised the total internal pressure above the saturation pressure and prevented boiling (not evaporation). It is more likely, however, that the mercury vapor displaced the lighter air to the inner ends of the cooled region of each thermosyphon element so that the vapor pressure was then equal to the total pressure in the system. The exact value of this pressure would depend upon the unknown internal and external heat transfer coefficients at the cooled ends of the elements, but within wide limits, the argument which follows is unaffected, qualitatively at least, by the saturation pressure. For the purposes of illustration it has been assumed constant at 30 lb. per sq. in., a mean figure consistent with the conditions of the tests.

Those parts of the wall of each element above the surface of the liquid column will have been in contact with either the vapor of the internal coolant or the condensate returning from the externally cooled ends of the thermosyphon. In the former case, cooling of the wall above the liquid column would have been negligible, and increasing the quantity of mercury would have increased the rate of heat transfer, contrary to the observations. In the second case the wall temperature would be substantially that corresponding to the saturation temperature of the mercury at the free surface, with a process of heat transfer by evaporation from a liquid film similar to that described in detail for water in the closed thermosyphon by Cohen and Bayley (1955).

The rates of heat flow from the heated ends of the element to the internal coolant, with the assumption that the only significant mode of heat flow is by evaporation, are represented by the areas between the lines corresponding to the distribution of saturation pressure at the different conditions tested and the horizontal line representing the constant gas temperature. Up to the condition at which the heated length is completely submerged in mercury, these areas are found to vary with filling quantity in a manner which almost exactly follows the observed variation in the rate of heat transfer through the thermosyphon elements, as is demonstrated in Fig. 18. In this figure the rates of heat transfer calculated from the curves of coolant saturation temperature and the heat transfer coefficient measured with the elements one quarter full are compared with the experimental results.

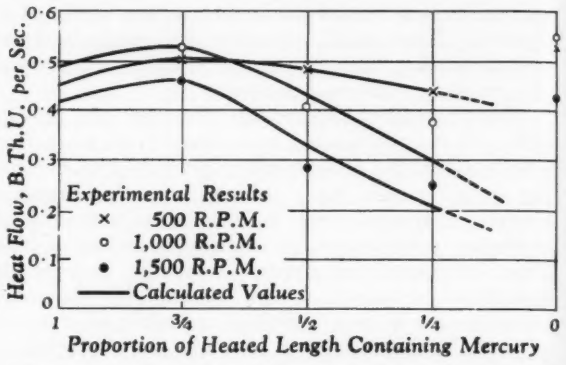


Figure 18. Comparison between experimental values of heat-flow rate and those calculated on the assumption of heat transfer by evaporation from the curves of Figure 17.

VAPOR PRESSURE

Better agreement between the calculated and measured results is obtained if the temperature-area integral for that part of the heated length above the liquid column is multiplied by a factor of 0.8. This factor can readily be accounted for by the observation by Cohen and Bayley (*loc. cit.*) in experiments with water in a static thermosyphon, that the returning condensate film did not completely cover the wall of the thermosyphon tube, an effect which would probably be increased in the present apparatus by the Coriolis forces acting. These tend to direct the film away from the leading surfaces, thus causing local cooling failure in these regions. Equally, however, the factor could be accounted for by variations in the internal vapor pressure which has been assumed constant, but which almost certainly is dependent upon the rate of heat flow.

In either case, however, the qualitative results, such as the decrease in the rate of heat flow observed under some conditions when the speed was raised or the quantity of internal coolant increased, are unaccountable unless the assumption is made that heat transfer to the internal coolant occurs when the heated length is less than full only by evaporation over the whole liquid column, and further, that the walls above the liquid surface are cooled by a film or series of rivulets of returning condensate and thereby contribute significantly to the heat-transfer process.

The increased rates of heat flow observed in the two test series in which the heated lengths of the thermosyphon elements were submerged in mercury can be explained by reference to the temperature distribution along the walls of the empty elements rotating at 1,000 r.p.m. drawn in Fig. 17. This curve was calculated from the measured rate of heat flow and the hot gas-to-elements heat-transfer coefficient deduced from the earlier tests referred to above, and is seen to lie below the saturation temperature curve drawn for the appropriate rotational speed. Thus when the heated length is submerged it is clear that no evaporation will occur and temperature gradients

in the elements, which were previously evened out above the liquid column by the condensate and vapor of the mercury which only partly filled the heated length, are created which contribute significantly to the rate of heat flow.

The severe temperature gradients along the columns of mercury in the closed thermosyphon elements of the apparatus here described, which appear to be consistent with the experimental results obtained, may need some justification since it would be expected, at first sight, that convective buoyancy forces due to the centrifugal acceleration in the rotating apparatus would even them out. For instance, if theoretical data on heat transfer by free convection in liquid metals (Bayley, 1955) is applied to the conditions of the tests reported here it is found that the rate of heat flow observed in the test with the elements half-full at 1,500 r.p.m. would be achieved with a mean temperature difference of only 1.8° F (1° C) between the inner walls and the coolant. At this condition, however, substitution of the relevant values of the properties concerned into the expression for the boundary layer thickness which is also derived in the theoretical paper cited, shows this to be about 0.26 in. at the free liquid surface, which is more than the internal diameter of the thermosyphon elements. A similar result is obtained for the other tests at the lower speeds. It is, threfore, clear that the geometry of the thermosyphon system will impose a severe restriction upon the rate of free convection circulation of the internal coolant, sufficient apparently, according to the results reported here, almost to damp out convective motion altogether.

CONCLUSIONS

The two significant findings of the experiments described in this article are, first, the evidence of a very severe restriction upon the convective circulation rate in the closed thermosyphon containing a liquid metal—mercury. Second, the more important, the evidence that mercury acts as a coolant by running over the heated surfaces of the elements as a film in the manner in which water was observed to behave in the experiments reported by Cohen and Bayley (1955).

The first of these two main conclusions is of less interest because the conditions in the rotary apparatus tested are much less favorable for the setting-up of a stable free convection circulation than will be those in a turbine, for which the heat-transfer system is finally intended. Thus, the maximum centrifugal acceleration achieved in the tests described here was 440*g*, whereas, as has been pointed out, values of up to 30,000*g* are quite likely in a gas-turbine rotor. With their higher centrifugal accelerations the boundary layers for a given rate of free convection heat transfer tend to be much thinner, and consequently the restriction on the circulation is reduced. In the discussion on the previous paper by Cohen and Bayley (1955), Dr. T. W. F. Brown gives details of results obtained on a rotating apparatus at Pametrada which suggests that at very high rotational speeds liquid metals can provide adequate rates of heat transfer in the closed thermosyphon by free convection alone with no change of phase.

The importance of the second main finding—that mercury appears to act effectively as a coolant in the form of an evaporating film—is that it suggests that the thermodynamic advantages of this fluid as a coolant for turbine blades may be utilized without the mechanical disadvantages normally resulting from its high density. If just sufficient mercury were sealed into a hollow turbine blade to ensure a complete film of liquid over the internal surfaces no hydrostatic forces would result and the only additional blade stresses resulting from the presence of the coolant would be those due to the vapor pressure. With mercury this need not be a serious factor to be taken into account, since for instance an operating blade temperature of 1,000° F (533° C) could be employed with an internal pressure of only 180 lb. per sq. in. The thermodynamic advantages of mercury as a coolant, in fact, lie in the possibility that it enables the whole range of practicable blade working temperatures to be utilized, and the particular value to be chosen from considerations quite unaffected by the internal heat-transfer characteristics of the cooling system. Thus with evaporation as the mode of heat transfer within the turbine blades, the internal resistance to heat flow may be considered negligible so that design of the cooling system is reduced to the

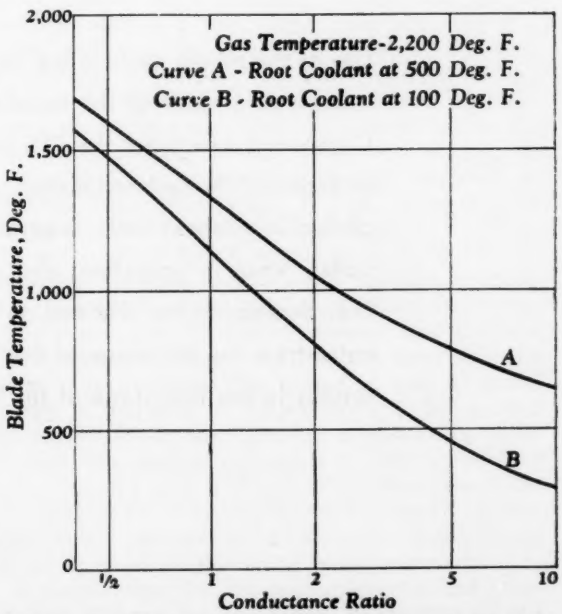


Figure 19. Effect of conductance ratio on turbine blade temperature. Much less severe heat-transfer rates are required at the blade root when higher operating temperatures are possible.

achievement of a suitable value of the conductance ratio, defined as

$$\frac{\text{heat-transfer coefficient} \times \text{surface area for heat extraction (at blade root)}}{\text{heat-transfer coefficient} \times \text{surface area for heat input (at blade span)}}$$

Fig. 19 shows how this parameter affects blade operating temperatures, and indicates the much less severe heat transfer rates required at the blade root when higher operating temperatures are possible than are necessary if undercooling is made inevitable by the characteristics of the many alternative liquid coolants which can be utilized in a thermosyphon system.

It is, therefore, clear that many advantages will result if mercury can be used as an internal blade coolant on the evaporating film principle previously observed to be possible with water. While the results reported in this article suggest that mercury can operate in this way, the conservative conditions of the apparatus used for the tests described, when compared with those of turbine operation do not enable a final definite conclusion to be drawn on this point. The urgent need now is for experimental confirmation, or otherwise, from a more advanced and elaborate apparatus than is possible in a University Department.

REFERENCES

D. G. Ainley, *Proc. Inst. Mech. E.*, London, vol. 167, No. 4, "Research on the Performance of a Type of Internally Air-Cooled Turbine Blade," 1953.

T. W. F. Brown, *Proc. Inst. Mech. E.*, London, vol. 162, No. 2, "Some Factors in the Use of High Temperatures in Gas Turbines," 1950.

T. W. F. Brown, *Proc. Inst. Mech. E.*, London, Thomas Lowe Gray Lecture. "High-Temperature Turbine Machinery for Marine Propulsion," 1954.

J. W. Keenan and J. Kaye, *Gas Tables*. John Wiley and Sons, Inc., New York, 1945.

D. W. Mallinson and W. G. E. Lewis, *Proc. Inst. Mech. E.*, London, vol. 159, "The Part-Load Performance of Various Gas Turbine Engine Schemes," 1948.

B. W. Martin, M.Sc., thesis, Bristol University: "The Part-Load Performance of a Double-Compound Gas Turbine," 1948.

B. W. Martin, Ph.D. thesis, Durham University: "Free-Convection Heat Transfer in the Vertical Open Thermosyphon, with Special Reference to Turbulent Flow," 1955.

H. Cohen and G. F. C. Rogers, *Gas Turbine Theory*. Longmans, Green and Company, 1951.

J. Hodge, *Gas Turbines, Vol. I, Cycles and Performance* Estimation. Butterworth Scientific Publications, 1955.

B. W. Martin, ENGINEERING. "Improving Gas Turbine Performance: Thermal Efficiency at High Temperatures." (Preceding article), 1957.

Sir H. Roxbee Cox (ed.), *Gas Turbine Principles and Practice*. George Newnes Limited, 1955.

W. R. Thomson, *The Fundamentals or Gas Turbine Technology*. George Over (Rugby) Limited, 1948.

F. J. Bayley, *Proc. I. Mech. E.* (B) vol. 169, No. 20, "An Analysis of Turbulent Free Convection Heat Transfer," 1955.

H. Cohen and F. J. Bayley, *Proc. I. Mech. E.* (B) vol. 169, No. 53, "Heat Transfer Problems of Liquid-Cooled Gas Turbine Blades," (1955).

Use of the reheat cycle in marine propulsion has gained recently renewed interest as a result of the installation on the Canadian Pacific Steamship Company's new liners the "SS Empress of Britain" and the "SS Empress of England." In each installation, the reheating for both turbines is accomplished in a reheat boiler separate from the two main boilers. The reheat boiler, when in operation, also supplies superheated steam to the main line, decreasing the demand on the two main boilers. The reheat steam enter from the last stage of the H.P. turbine at 175 psig and 612° F and returns to the first stage of the I.P. turbine at 165 psig and 850° F.

DAVID W. SALTUS

SOUND OVER THE SEA

THE AUTHOR

received his Bachelor's degree in Electronic Physics from Harvard University in 1945, and his Master's in 1948. He served in the Navy during World War II as a Radar Officer. He has taught Physics and Mathematics in the intervening years. Since 1955, he has been associated with Reed Research, Inc., Washington 7, D. C., working in the field of acoustics, particularly sound propagation.

SOUND phenomena play a special role in the lives of ship designers and ship operators. Anyone who has lived aboard a vessel in repair dock with pneumatic tools for shipmates is painfully acquainted with this uncomfortable aspect of acoustics. In addition, there are few walks of life where the safety of equipment and personnel depends so much upon the interpretation and production of sounds which have travelled or will travel over long distances. Bells, diaphones and whistles still cry of danger in the fog; shouts and hails still have a utility not yet outgrown. However, in spite of such experience with sounds, it is suspected that most maritime workers know very little about the basic physical laws which govern sound propagation. How many times do Captains fail to use weather information in estimating the range of audibility of a fog signal? How many times are the specifications for a fog warning device written from the manufacturers' catalogs? Much too often, it is feared. The fault is not completely the mariner's; the topic of sound signals over the sea is seldom covered in the periodicals he usually reads. To a large extent, the information he could use is scattered through the acoustical literature, often within articles which deal primarily with other issues. This article is a summary of this scattered information arranged, it is hoped, in such a way that it will prove useful to the designer or operator when he is presented with situations similar to those outlined above.

For the sake of continuity and to remain practical, the relevant technical information is presented as the answer to a question, namely: what factors cause a sound signal to fall in intensity as it increases in distance from its source?

The order of intensity magnitudes might be noted at this point. At its extreme of sensitivity, the ear responds to a pressure on the drum of .0002 dynes/cm^2; a fog horn might produce a pressure of 2×10^8 dynes/cm^2 near its throat. The horn is a million million times stronger than the threshold level of the ear. This discrepancy in magnitude suggests that the initial question could be put in a less stilted form; the fundamental question might well be: why can we not hear our warning devices further than we do?

One reason we cannot lies in the fact that the energy in a sound wave usually spreads out over a larger and larger area as the wave moves away from the source. The amount of energy crossing a given area of space becomes less and less just as the thickness of a paint layer must decrease if a larger wall is to be covered. In many of the cases which occur in practice (e.g. low frequency devices like fog horns); it is possible to assume that the sound waves diverging from the source are in the form of expanding spheres. When this assumption holds, it follows that the intensity falls inversely as the area of the sphere which, in turn, varies directly as the square of the distance from source to wave. The acousticians find it useful to measure this relationship between intensity and distance in terms of a logarithmic unit, the decibel. (See Reference 1.) In these units, the loss in intensity due to spherical spreading amounts to 6 decibels each time the distance is doubled. The spreading out of sound energy is therefore an important loss factor near the source, since the intensity decreases by 6 db whether the change in distance is from 1 foot to 2 feet, or from 1 mile to 2 miles. Consideration of the geometry of the situation makes this result reasonable, since spheres of great radii approximate planes upon which there will be no spreading.

A second cause for the diminution of sound energy with distance may be found by considering the nature of the medium in which it is propagated. To form a somewhat naive picture, it can be imagined that the molecules moving with the sound wave rub

against each other, degrading the sound energy to thermal by friction. The compressions and rarefactions of the air which make up a sound wave also vary in temperature with consequent flow of thermal energy from one to the other. While this last is not a friction loss; the ultimate result is the same, i.e. sound energy is changed to thermal. All mechanisms which lead to thermal losses are usually grouped together and collectively known as absorption effects. At low frequencies such effects are small; since absorption is dependent upon the square of the frequency, it cannot be neglected at the higher pitches. (See Table 1 which gives representative values of absorption calculated from theoretical consideration of the particular loss mechanisms described.)

TABLE 1—*Theoretical Values of Absorption*

Frequency	Absorption db/1000 ft. at 0°C
10	4×10^{-6}
100	4×10^{-4}
200	1.6×10^{-3}
300	3.6×10^{-3}
400	6.4×10^{-3}
500	1.0×10^{-2}

An idea of the impossibility of explaining observed ranges of audibility as the result of spreading and simple absorption may be gained from an inspection of Figure 1. This figure was prepared by simply assuming that spreading and absorption constitute the only loss mechanisms. It was further assumed that the useful range of the signal was reached when its level became 20 db. Admittedly, twenty db is a compromise figure which recognizes both the fact that one never can listen in a region of absolute quiet and the fact that the ear cannot hear sounds as low as zero db at all frequencies. Using this arbitrary and somewhat suspect limiting level, as well as the formulas of Table 1, it is a straightforward matter to assume a source intensity at 100 feet and then to compute how many times the 100 feet must be doubled to lower the intensity to 20 db.

One conclusion becomes immediately apparent when examining the graph that results: simple absorption is usually negligible in comparison with the 6 db fall-off due to spherical spreading. The break in the curves of Figure 1 match the frequencies above which absorption losses need be considered; many maritime signals lie below these points and never reach the longer ranges. If a concrete example is taken, a second conclusion becomes apparent: Figure 1 is completely unrealistic. As an example, the Queen Mary's whistle produces 113 db at 100 feet. The operating frequency, or frequencies, are probably low; if a single frequency output at 300 cps is assumed and Figure 1 is entered, the curves indicate a useful range of over one hundred miles for the device. Needless to say, this result is ridiculous.

Arguments similar to the above have long led to the conclusion that spherical spreading and absorption are not sufficient explanations for sound attenuation. The comparison of predictions from Figure 1 with anyone's experience establishes the point; numerous measurements of sound attenuation have also confirmed the inadequacy of the simple theory.

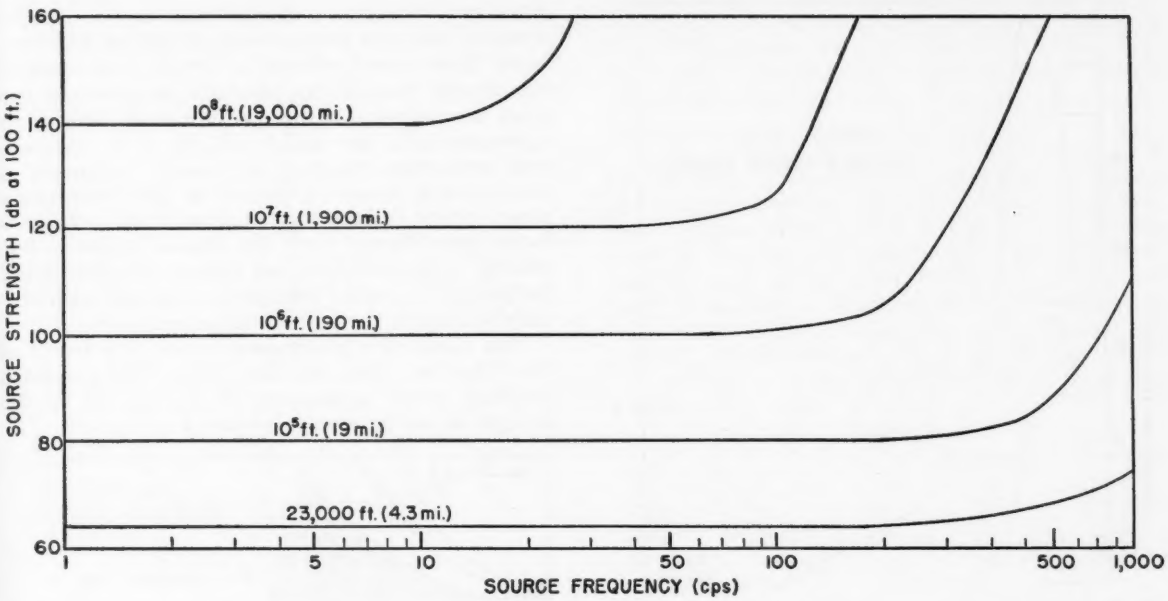
TABLE 2—*Measured Values of Sound Absorption*

Frequency	Avg. Min. Absorption db/1000 ft.	Avg. Max. Absorption db/1000 ft.
125	.44	1.0
250	.36	1.49
500	1.08	2.58

Table 2 lists the result of one such study. The figures shown are the values of the attenuation, α, in db/1000 ft., which remained after the data had been corrected for spherical spreading and absorption. It will be noted that this residue is considerable. Figure 2 has been prepared to show how considerable this residual attenuation really is by displaying a comparison between losses due to it and the losses due to spherical spreading and absorption. On Figure 2, the curved line represents the spherical spreading loss at various ranges. At any range, this curve gives the value which must be subtracted from the signal level at one foot to give the level at the new distance. The straight lines represent similar corrections to the level at one foot due to various values of α, the attenuation in db per 100 feet. It will be noted that the values of Table 2 lie near the two straight lines on the far right. It will be further noted that attenuation factors calculated from Table 1 would not even be perceptible if plotted on the scale of Figure 2; as has been stated, theoretical absorption is often negligible. We can use Figure 2 for yet another purpose—for recomputing the range of the Queen Mary's whistle. The level of this device is 153 db at one foot (see Reference 1). At approximately 35,000 feet, Figure 2 shows that the spreading and attenuation loss add up to approximately 150 db; thus, 6 or 7 miles is indicated as a very generous upper limit for the range of audibility of the Queen Mary's whistle. This result is much more consistent with observations than was the previous estimate.

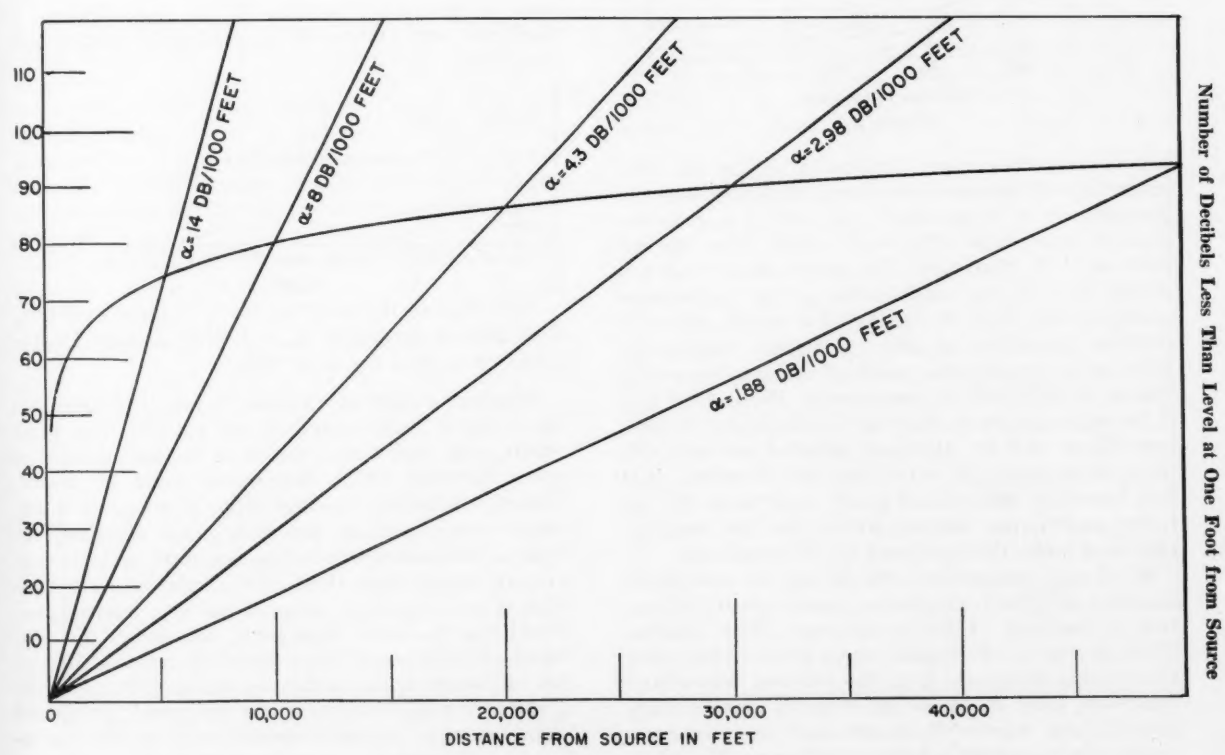
From these considerations we arrive at what might be called the acoustical sixty-four dollar question. What causes experimental measurements of attenuation to be so high? Why this wide disparity between actual observations and predictions made from the simple theory? The full explanation is not simple; sixty-four dollars does not begin to approach the money spent on propagation studies, and in spite of the research the experts are uncertain as to all the details. It does appear, however, that there are in all ten factors which affect the range of a sound signal. Two have already been mentioned, spreading and absorption, and four more, the more important, will be commented upon below. These four are humidity, temperature, wind, and ambient or background noise level.

The humidity present in the atmosphere has a curious effect upon the passing sound wave. Water molecules apparently catalyze a packing loss asso-



Theoretical Ranges

Figure 1



Divergence and Absorption Compared

Figure 2

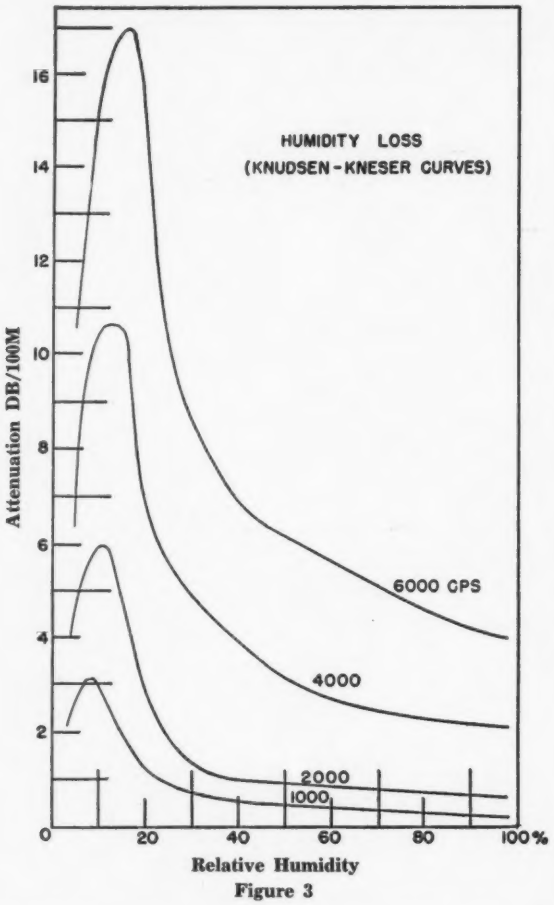


Figure 3

ciated with the oxygen molecules of the air. The magnitude of the resultant loss is dependent on the humidity in a complicated way, which is best described by a graph (Figure 3) taken from the reports of V. O. Knudsen.[3] The graph shows that humidity loss can be considerable at the higher frequencies and that it "peaks" for some value of relative humidity at any particular frequency. When it is recalled that most of the intelligence in speech is conveyed by frequencies above 2000 cps, it becomes apparent that the intelligibility of hails and shouts will be adversely affected on very dry days particularly. It is not thought, however, that this humidity factor is of great importance for fog horns and similar devices where the low frequencies used make the loss small at all humidities.

Wind and temperature effects may be considered together since both produce a similar effect—refraction or bending of the sound rays. This bending often results in a decreased range of audibility since the wave is bent away from the receiver who would otherwise hear it. To be as brief as intelligibility permits, any wave will be refracted as it enters a medium in which its velocity is different. If a plane wave enters a region of lower velocity obliquely, it will "stub its toe," so to speak, on the slower medium and bend more sharply into it; the reverse occurs if the new region is one of higher wave velocity. Since sound velocity is directly dependent on the square root of the absolute temperature and since the velocity of the medium itself adds to or subtracts from the sound velocity, it is apparent that refractive bending will occur whenever a sound wave enters a region of the atmosphere where either or both the temperature and wind velocity are different from the region originally traversed. It can be shown that regions in which either temperature or wind change continuously with altitude will curve the path of the sound waves.

Two interesting phenomena occur as a result of this—shadow zones and channeling. When upward bending occurs, a shadow will be formed by the ground as can be seen in Figure 4.

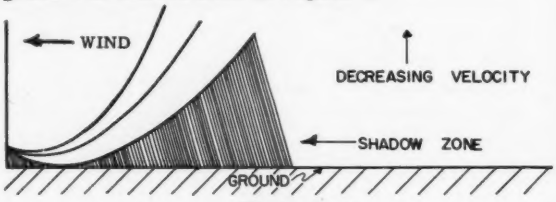


Figure 4

Such a shadow is not as sharp or as total as an optical shadow, but the sound intensity is much diminished in the region. An important case of channeling can occur downwind when conditions favor a downward bending of the rays—Figure 5. Audibility can extend for long distances under such conditions.

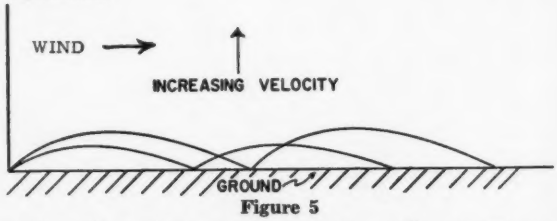
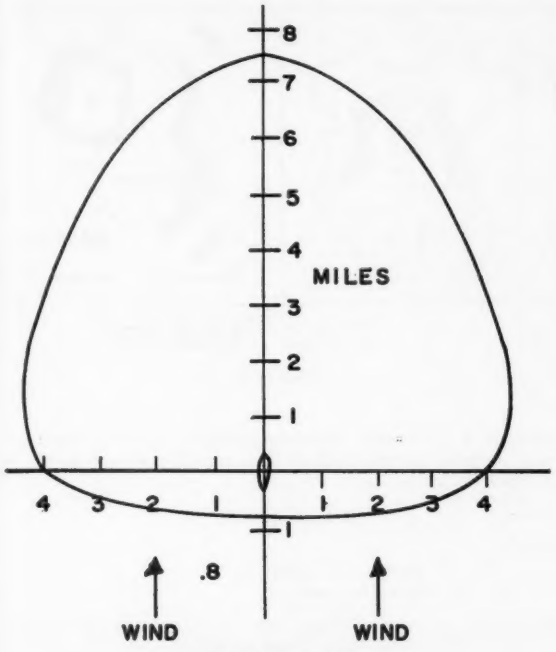


Figure 5

The effect of the wind is clearly evident in Figure 6—a plot of the limits of audibility around Boston Light Ship, data taken in 1930.[4]

Weather conditions impose a practical limit on the range of sound signals in yet another way. High winds, rain, and storms can raise the background of noise through which the signal must be heard. Noises originating on the ship, propulsion noise, water noises against the hull, crew activities, as well as sea noises due to the sea state or to breakers, all noises from these and similar sources produce a masking effect upon an ear or a microphone. From the practical standpoint, therefore, the ambient or background noise must be included in any list of factors which influence the audible range of a sound signal. Unfortunately, not much published information is available which would enable one to estimate the average magnitude of typical ambients at sea. Strangely enough, it is much easier to predict the ambient levels in the water under the ship

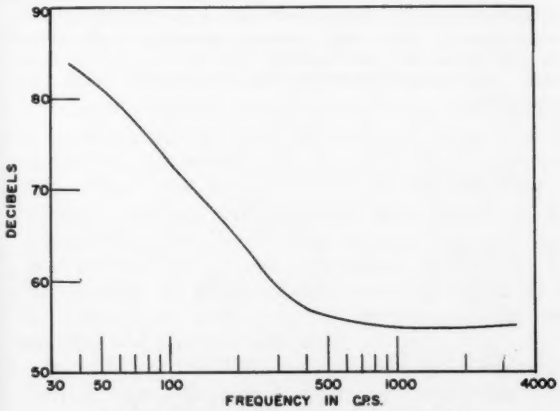


Audibility Around Boston Lightship September 18, 1930 —Line of Perception

Figure 6

or in the machinery spaces than it is to predict above deck levels. One figure is available which can be used to estimate the ambient. In the evaluation and development of fog horns the Coast Guard customarily assumes that a 55 phon[5] signal will be heard above the usual ambients at sea. Using the definitions of Reference 5, this value of 55 phons can be used to derive a curve of the typical ambient at sea. The result is shown in Figure 7.

The levels of the derived Coast Guard ambient make it apparent that Figure 1 is in error in yet another way. It will be recalled that a uniform ambient of 20 db was assumed in preparing Figure 1; Figure 7 indicates that this value was too low. Figure 8 shows the result of correcting Figure 1 with the ambient levels of Figure 7. An inspection of the theoretical ranges which result indicates that typical ambient levels do not impose the severest limit on the range of an airborne sound for frequencies above approximately 100-200 cps. At the higher frequencies the range curves would, of course, rise again as the absorption increased. There is, therefore, a band of optimum frequencies insofar as range is concerned. This has evidently been recognized in the design of fog horns; Table 3 shows the operating frequencies of several such devices. These frequencies lie in the optimum range as shown on Figure 8.



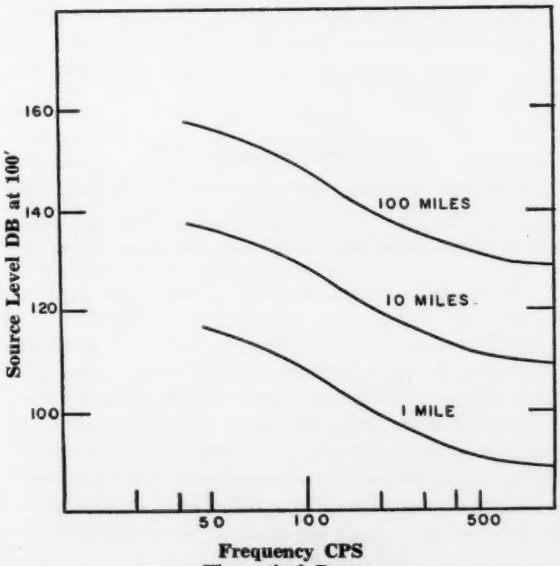
Ambient Presumed by the Coast Guard

Figure 7

TABLE 3

	Fundamental	Harmonics
425 mm Tyfon	92	184,276
200 mm Tyfon	103	206,309
200 mm diaphragm	110	260,390
Diaphone	115	230,345

Finally, and in summary, it may be said that the question proposed at the beginning of this article can, at present, be answered only in a general way. This survey has, of necessity, been brief; however, enough has been included for the reader to appreciate that there exists no simple or accurate way of predicting the sound level which will exist at a given distance from some specific sounding device. This article has not touched upon reflection, absorption by the ground, diffraction, or scattering all of which have a complex effect upon the levels. It is hoped that enough information has been included



Theoretical Ranges

Figure 8

to serve as the basis of useful, although somewhat qualitative, judgments.

For example, the range curves should prove useful in the evaluation or design of new warning signals. Then, too, an appreciation of the effects of the wind and temperature structure of the atmosphere should prove useful in both explaining and predicting departures from the usual range of a fog signal or a bell. Good listening practices may be devised; the difference between Figure 8 and Figure 1 emphasizes the importance of maintaining low ambient levels at listening positions on a ship. It will also be noted that calculations of the spherical spreading loss give a quick, approximate estimate of the minimum loss that may be expected in the majority of propagation problems over the sea.

Conditions near the earth's surface are such that sound devices do not reach the ranges which might be expected from considerations of the energies in their outputs. It is natural to speculate upon the possibility that existing limitations could be removed and that longer ranges could be obtained. Evidently, the possibility does exist, and the speculation is not idle. Extremely long range sound signals have been observed in studies of what have been called abnormal sound waves. These are the waves, produced in all recorded instances by large explosions, which have traveled to the increasing temperature region of the high stratosphere and from there have been refracted to the ground, i.e., these waves have traveled through regions which are more homogeneous than those near the earth's surface. Figure 9 gives an example of the ranges which occur. One cannot help but wonder whether either warning or communication devices could be devised which would use these waves. There is one great drawback, however; abnormal waves are infrasonic. Nevertheless, it does seem possible that research could produce a suitable, economical device which would allow mariners to benefit from the long ranges typical of the low and very low frequency sounds.

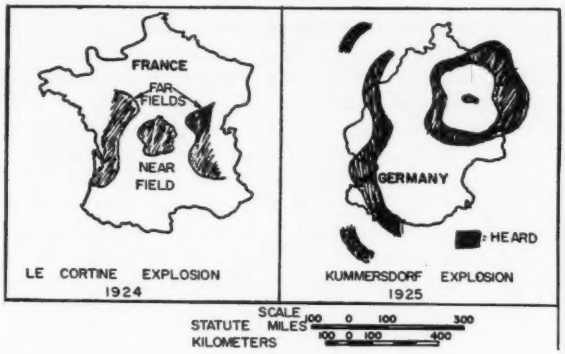


Figure 9

FOOTNOTES AND REFERENCES

[1] Some confusion has arisen regarding the meaning of this term. Since the root mean square of the sound pressure variations may, in practice, vary from at least .001 dynes/cm^2 to 20,000 dynes/cm^2, it is more convenient to express them in a contracted logarithmic form. The unit used for this purpose is the decibel. The sound pressure level, in decibels, is given by:

$$20 \log 10 \frac{P}{P_o}$$

where

P = the pressure in question
P_o = a reference pressure

For sound in air and water, the reference pressure usually used is .0002 dynes/cm^2. A source of confusion lies in the fact that 1 dyne/cm^2 has in the past been used as the reference pressure for underwater sound. It is important that the reference level always be stated. In this paper .0002 dynes/cm^2 is the reference.

[2] Delsasso and Leonard, "Attenuation of Sound in the Atmosphere," AF Contract W-28-099, AC-228. February 25, 1953.

[3] Knudsen, V. O., "Absorption of Sound in Gases," *Journal Acoustical Society of America* No. 7, page 199 (1934).

[4] Hubbard, "Influence of Atmospheric Conditions on the Audibility of Fog Signals," *Journal Acoustical Society of America* No. 3, page 11 (1931-32).

[5] A unit used to define the loudness of a complex sound in terms of sound pressure level is the phon. This loudness level, a measure of subjective sensation, is defined as the sound pressure level of a complex sound which is judged by listeners to be equivalent in loudness to a pure tone of 1000 cycles per second. At 1000 cps a loudness level in phons is numerically equal to the sound pressure level in decibels. The loudness level relative to the sound pressure level varies with amplitude as well as frequency. Many acoustic references include graphs which allow one to convert loudness levels in phons back to sound pressures in db referred to .0002 dynes/cm^2. See Randall, "An Introduction to Acoustics," Addison-Wesley Press, Inc., Cambridge, Mass., 1951, page 215.

U.S. NAVAL RESEARCH LABORATORY

NAVAL RESEARCH LABORATORY NUCLEAR REACTOR

ACKNOWLEDGEMENT

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BACKGROUND

The Naval Research Laboratory Nuclear Reactor (Figure 1) and its associated facilities for research were designed to meet the needs of a wide variety of investigations in the physical sciences. Its principal function is to provide a powerful source of neutrons, required in many aspects of the Laboratory's research programs in such fields as nuclear physics, solid state physics, metallurgy, chemistry, mechanics, electronics, and reactor technology.

Initial planning began late in 1952. In the summer of 1954 the Congress appropriated $996,000 for construction, which was begun in mid-1955. The reactor was brought critical for the first time on September 17, 1956.

Pursuant to a stipulation of the Congress when it authorized construction of the NRL Reactor, the installation was built and is operated under license from the U. S. Atomic Energy Commission in accordance with provisions of the Atomic Energy Act of 1954. The men who operate the controls of the reactor are individually licensed by the A.E.C. as operators.

UTILIZATION FOR RESEARCH

Neutrons—small sub-atomic particles or fragments of matter which are given off when the reactor is operated—are extremely useful in numerous investigations. They may be used to study the structure of matter, including such practical applications as the structure of new alloys. They may be used to create new substances; to make chemicals radioactive for direct study, or after radioactive decay for study of the new decay products; and to produce chemical changes and biological changes.

In addition, the NRL reactor is suitable for investigating many problems arising in connection with the design and operation of nuclear reactors whose heat is used to propel ships or other vehicles or to drive electrical generators.

DESIGN AND OPERATION

The pool type reactor design was chosen because of its flexibility for research and its inherent safety characteristics. Reactors of this general type have been operated safely at other locations for several years.

The pool is located approximately in the center of a structure 60 ft wide and 210 ft long (Figure 2). At each end of the building are located laboratories and offices, as well as a large "hot lab" where work can be done by remote control on highly radioactive materials, and a shielded room for accurate measurement of radioactive materials. The pool is 40 ft long, 26 ft wide, and 20½ ft. deep. One end of the pool consists of a heavy concrete radiation shield with a number of openings or "beam ports" in it providing access to neutrons.

The fissionable material in which the nuclear chain reaction or "burning" occurs is uranium 235. It is contained in fuel assemblies which are suspended in the water on an aluminum framework mounted at the middle of a movable platform or bridge which spans the pool. The array of fuel assemblies is called the "core" of the reactor (Figures 3 and 4). The bridge rides on rails making it possible to locate the core at any point on the center line of the pool.

The water serves three purposes in this type of reactor. First, it slows down the fast-moving neutrons (average speed about 10,000 miles per second) which are released when a uranium 235 atom splits in half or "fissions". The slower-moving thermal neutrons (average speed about one mile per second) are more reactive with other uranium 235 atoms, causing them to split and yield additional neutrons; thus the presence of the water reduces the amount of uranium 235 necessary to sustain a nuclear chain reaction. Second, the water serves as a coolant to remove the heat formed in the uranium by the reaction, and, finally,

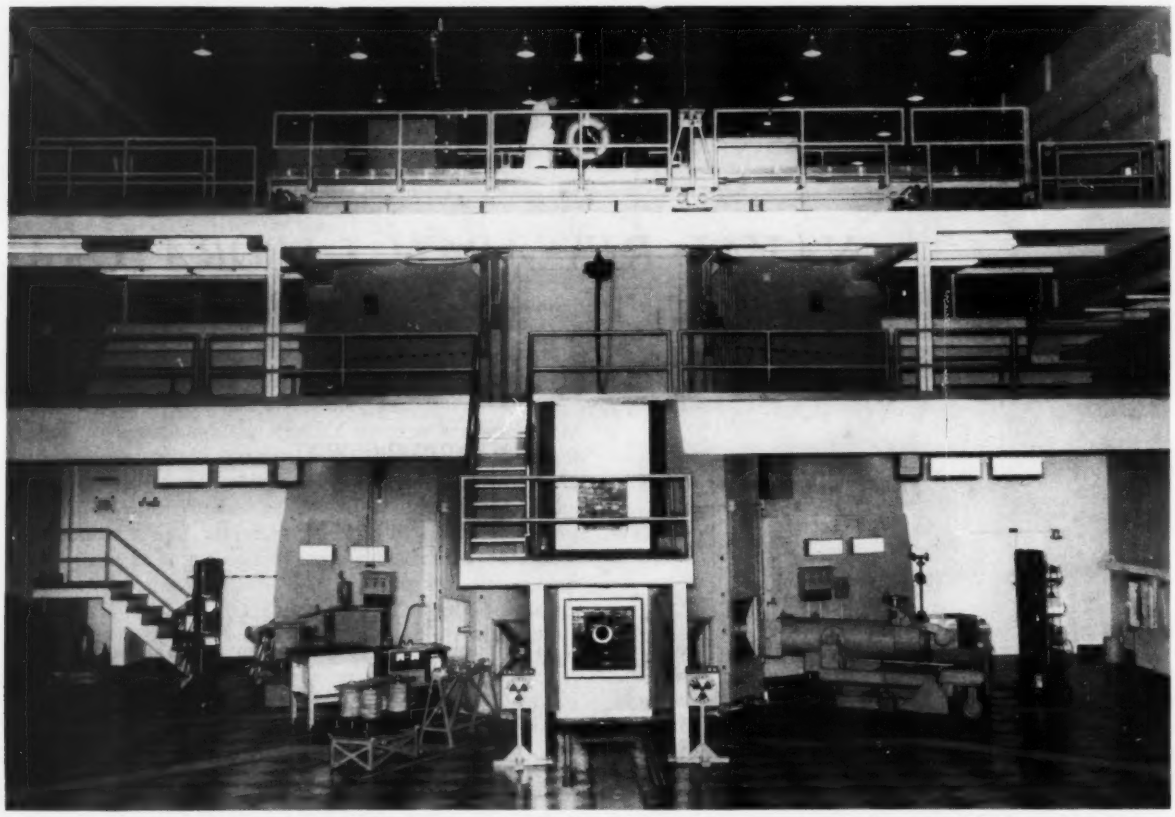

Figure 1. One end of the pool terminates in a special radiation shield of lead, concrete and other materials. A number of openings or beam ports penetrate this shield permitting neutrons from the core to emerge under controlled conditions for use in physics research.

it is a radiation shield which protects personnel from the harmful neutrons and gamma rays generated in the uranium fuel. The gamma radiation from the core after 8 hours operation at 100 kilowatts is roughly equivalent to that from a ton of radium.

The first several months of operation of the reactor were devoted to a series of tests and calibrations at low power levels. The entire control system was given thorough testing. The control and safety rods and various instruments were calibrated. The minimum amounts or "critical masses" of uranium 235 required for operation in different positions in the pool and for various core loading configurations were determined, and a number of other operating characteristics of the reactor were measured. The reactor was formally opened for research on January 15, 1957.

FUEL ELEMENTS AND REACTOR CORE

The uranium fuel of the NRL reactor has been enriched to 90% uranium 235, the remainder being uranium 238. The basic fuel unit is a plate 60 thousandths of an inch (about 1/16 inch) thick. Each plate is in reality a sandwich; the center 20 thousandths is uranium-aluminum alloy, and a layer of aluminum cladding 20 thousandths inch thick is bonded to each side. The cladding seals in the radioactive product elements formed by the splitting of uranium 235 atoms, preventing the former from contaminating the pool and air. A fuel assembly consists of 18 of these plates spaced about 1/9 inch apart, and contains a total of 140 grams (about 5 ounces) of uranium 235. Each assembly is open at top and bottom. Water flows up through the assembly by convection, passing between the fuel plates and removing the heat formed during operation.

If the reactor were operated regularly for 40 hours per week at a power level of 100 kilowatts, a set of fuel elements containing about 11 pounds of U-235 would last for approximately 40 years. At the end of that time only about 10 per cent of the uranium would have been burned up; however, certain of the product elements of fission formed in the fuel plates absorb neutrons necessitating replacement of the fuel assemblies. The spent units will be shipped in lead containers to special fuel processing plants where the fuel plates will be dissolved in acid and the unburned uranium separated chemically and recovered for further use.

The useful life of the fuel assemblies is proportionately shortened by operating the reactor at higher power levels or for longer periods each week.

In several special fuel assemblies half of the plates have been omitted to provide an open channel for insertion of control and safety rods (Figures 3 and 5).

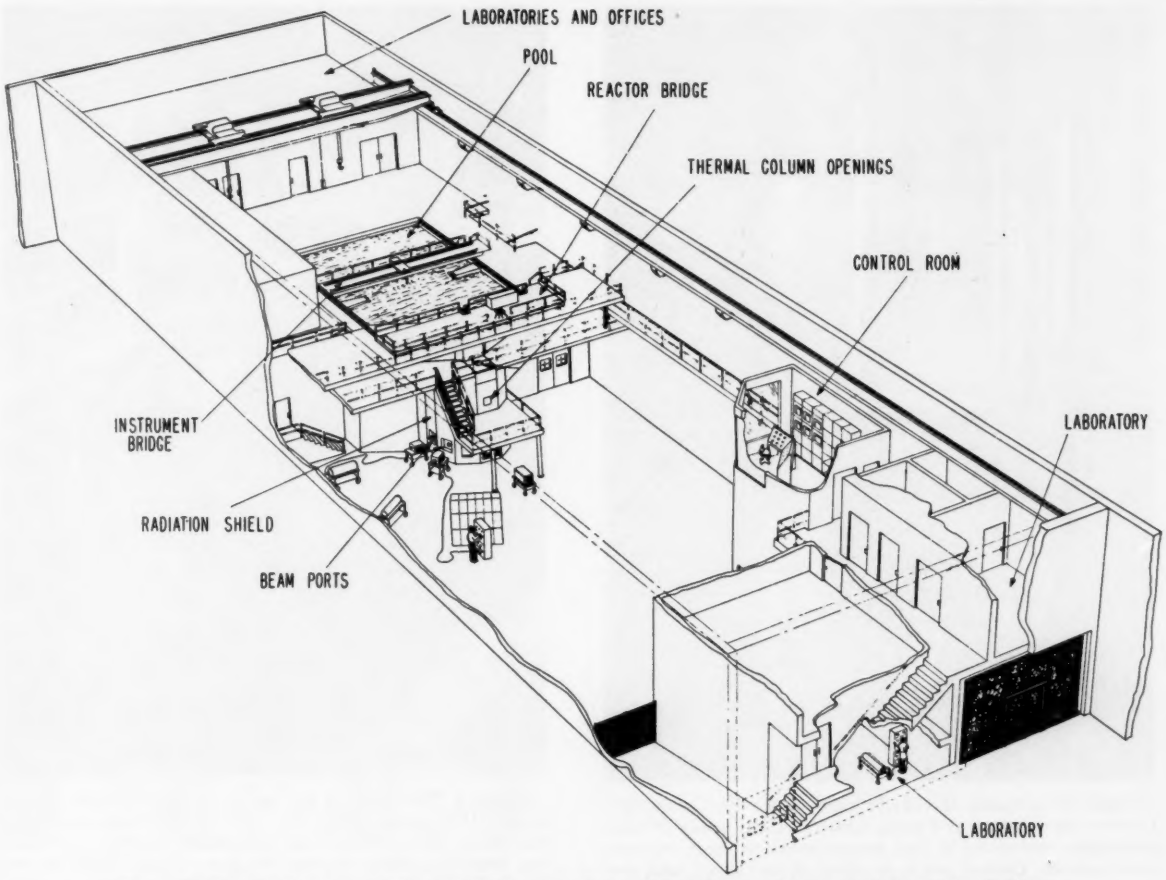

Figure 2. The uranium core of the reactor is suspended in the pool from the center of the reactor bridge.

A control or regulating rod of stainless steel is moved up and down in one of these channels to regulate the power of the reactor. Two or three other rods containing boron, a highly absorbing material for neutrons, are inserted in other fuel assemblies in the core as a safety measure to provide for rapid quenching of the nuclear reaction if needed. These safety rods are also sometimes called shim rods, since by raising or lowering them slightly coarse adjustments are made in the power level.

The core of the reactor consists of a group of fuel assemblies arranged side by side in a generally square array. As few as 17 or as many as 30 fuel assemblies may be required to sustain a chain reaction, the exact number depending on the configuration used and the materials immediately adjacent to the fuel in the pool.

HOW THE NUCLEAR REACTION IS STARTED

In starting the reactor, the safety rods are withdrawn from the core first and held in reserve for emergency shutdown, then the control rod is withdrawn far enough to permit the neutron chain fission reaction to become self-sustaining.

The initial neutrons required to start the reaction are supplied by a "neutron source," a small sealed capsule about the size of a thimble containing radioactive polonium and the element beryllium. This is located at the edge of the core adjacent to the fuel assemblies.

As the reaction is started, the concentration of neutrons is measured by a fission chamber located adjacent to the fuel, and the information is displayed in the control room. When the neutron concentration or "flux" has increased somewhat, other detectors take over the measurement function and the sensitive fission chamber is withdrawn from the core. When the reaction becomes self-sustaining the neutron source is also withdrawn from the region of the fuel.

The neutron flux is permitted to increase gradually until the desired operating power level has been reached, at which time the control rod is moved in slightly, then continuously adjusted either manually or automatically, to maintain that level.

Each safety rod is coupled to its drive rod by an electromagnet. If an undesirable condition should develop, the current to the magnet is interrupted and the rod falls by gravity into the core, stopping the nuclear reaction.

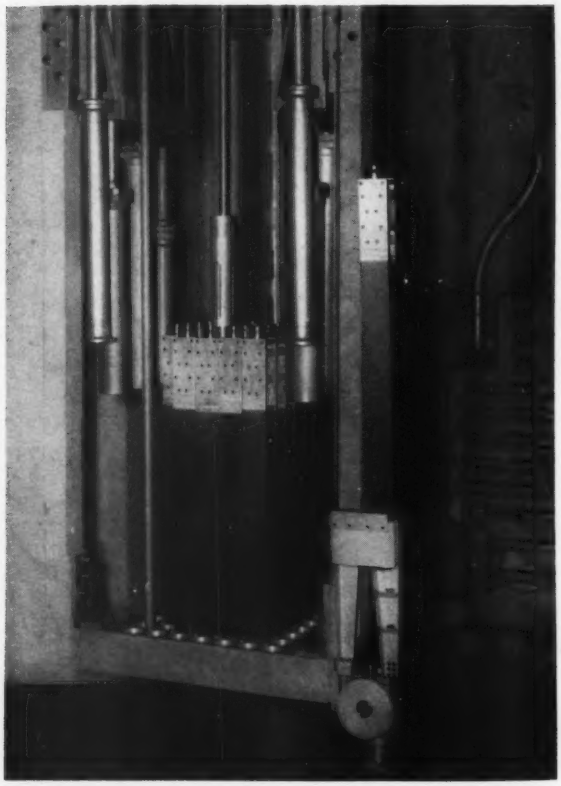

Figure 3. Closeup of reactor core shows fuel assemblies (center) mounted on grid plate, which has 7 x 7 array of holes permitting variations in fuel arrangement to meet research requirements. Control rod is in center of fuel array, with two safety rods behind it. Slender tube at left contains movable neutron source for startup. Fuel assembly at right is mounted on elevator which runs up to water surface. Recess in shield and "rabbit" tube are visible in background.

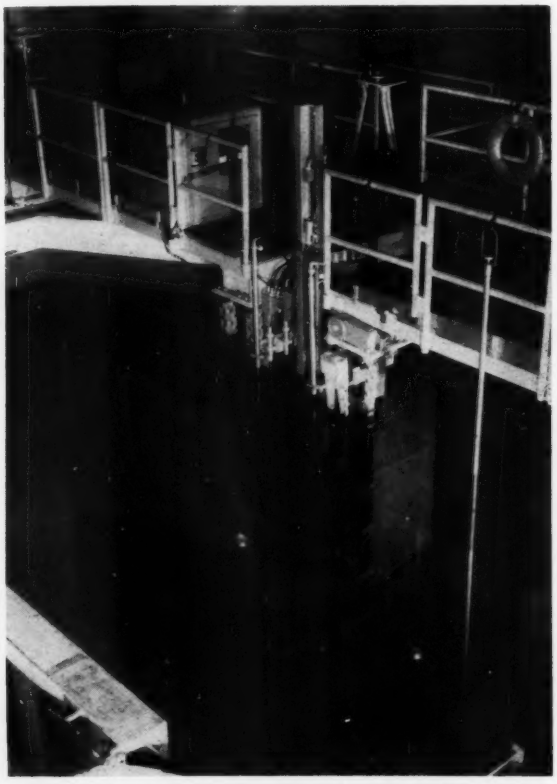

Figure 4. The heart of the reactor is the uranium core located in the pool at the bottom of the trusswork attached to the bridge. The cylinders on each side of the fuel are radiation detectors which measure the power level of the reactor. Except for the fuel units, the entire bridge and core assembly, including the detectors, was fabricated by the Laboratory.

THE REACTOR CONTROL SYSTEM

The eyes and ears of the control system are the radiation detectors located on each side of the core. The hands of the system are the safety and control rods. The remainder of the system consists of motors to drive the rods up and down, instruments to display and record the signals from the detectors, a control console, and a complex electrical and electronic system connecting these and including many interlocking features to provide maximum safety in operating the reactor. The control system was designed in its entirety by NRL scientists and was constructed and assembled in the special shops of the Laboratory. The detectors were designed and constructed at NRL, as was the control console.

THE SHIELD

The shield has several unique construction features (Figures 6 and 7). It was desirable to keep its thickness to a minimum so that the beam ports would be as short as possible in order to provide more intense neutron flux at the outer ends of the ports. Special concrete was used to reduce the shield thickness required. The heavy aggregate on the side toward the core is barytes, a barium sulfate rock, barium being a strong neutron absorber. In sections of the shield behind the barytes portion, the heavy aggregate is iron ore and iron punchings, a good gamma ray shield. The aggregates were placed dry in the forms. A cement-water mixture was then pumped up through the mass in a single operation.

In the center of the shield just behind the reactor core recess is a stack of graphite blocks called a thermal column, roughly 3½ ft x 4 ft and 9½ ft high. Graphite is a dense form of the element carbon, which is a good medium for slowing down neutrons to thermal velocities—somewhat better than water, in fact. Two openings near the top of this column provide sources of thermal neutrons where these are required in particular experiments.

The seven beam ports which penetrate the concrete and carbon provide sources of fast or fission-energy neutrons. In addition to these openings there is a "through-hole" passing alongside the core, which is convenient for certain types of experiments. These holes penetrate the graphite blocks at various angles. The blocks in this region of the thermal column were

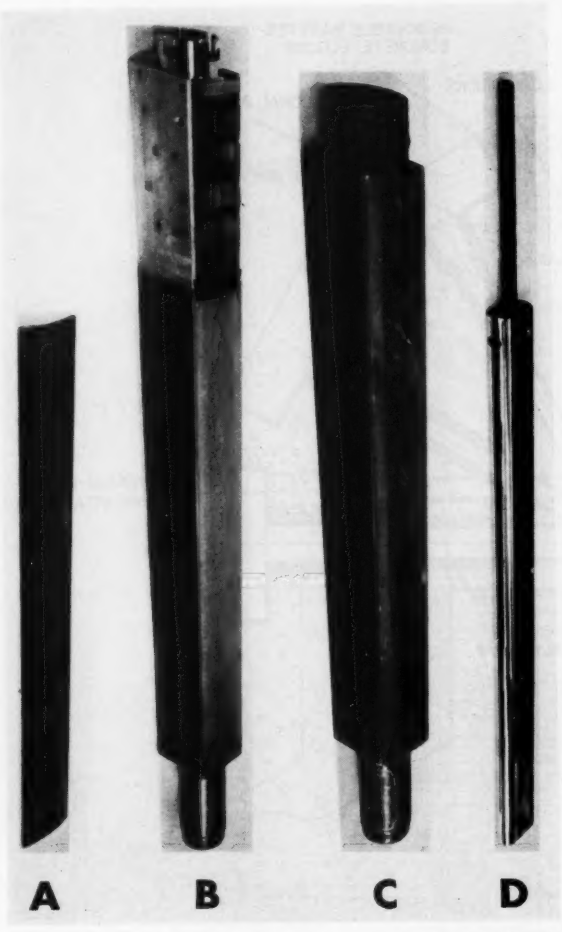

Figure 5. A single fuel plate (A) is essentially a thin aluminum sandwich containing 8 grams, about ¼ oz. of uranium 235 in a layer through the center.

A fuel assembly (B) is made up of 18 plates spaced a small distance apart to permit water to flow between them for cooling and neutron moderation. It contains 140 grams, or about 5 oz. of uranium 235.

In several special fuel assemblies (C) 9 of the center plates have been replaced by an open channel in which the neutron-absorbing control or safety rods are inserted.

Movement of the stainless steel control rod (D) up or down in the array of elements comprising the core controls the nuclear reaction.

fastened in a jig and the holes bored through the entire assembly on a large boring mill in the NRL shops.

The graphite region extends out on each side of the core recess or niche. The graphite immediately surrounding the core is sometimes called the "reflector" because many of the neutrons which are slowed down in this region diffuse back into the core. When the core is in the niche it is graphite-reflected on three sides and water-reflected on the remaining three surfaces. Since graphite is a better reflector than water, less fuel is required to constitute a critical mass in the niche than out in the pool. Because the neutron density for a given power is greater around a smaller core, this arrangement also increases the available neutron flux at the ends of the beam ports.

The water barrier in front of the graphite and the beam ports is a sheet of aluminum half an inch thick, which is essentially transparent to neutrons and gamma rays. The edges of this aluminum skin are recessed in the concrete. The recessed portion is coated with zinc to prevent corrosion of the aluminum by the concrete.

The aluminum skin has up to 20 feet of water head against it, requiring that it be strengthened from behind to withstand the pressure at this depth. The use of metal reinforcing plates would have replaced graphite where it was most needed close to the core as a reflector. Tests of the graphite bars showed that they had more than enough strength to be used also for mechanical reinforcement, and a row of them is bolted to the back of the aluminum plate to prevent it from buckling.

THE "RABBITS"

A special facility available for the irradiation of small quantities of materials is a system of pneumatic tubes in which small carriers called "rabbits" may be moved quickly by compressed air. Two rabbit terminals are provided near the core in the niche position. Depending upon research requirements, samples may be irradiated here for a few seconds if desired, or for longer times. The containers may then be returned to lead-walled receiving boxes outside the shield or directly to remote receivers near the laboratories in the facility.

THE POOL

High purity water is used in the pool to minimize corrosion of the thin aluminum cladding on the fuel elements. City water is further purified by passing it through a special treatment plant in the reactor building.

The pool may be divided in half by positioning a movable water gate across its center, making it possible to drain half the pool while the reactor is being operated, or the radioactive core is stored, in the other half. This increases flexibility of operation. The half of the pool farthest from the shield may be used for investigations aimed at improving methods of calculating radiation shielding requirements, optimizing shield arrangements and materials, etc. It may also be used as a gamma ray irradiation facility using radioactive fuel elements as a gamma source.

The pool, which holds 150,000 gallons, drains to an underground tank of 170,000 gallon capacity. Contents of this holdup tank are carefully analyzed by health physicists to assure that any radioactive materials are below tolerance levels prescribed by the AEC before discharge to the Potomac River.

THE HIGH RADIATION LABORATORY OR HOT CELL

A room heavily shielded by concrete called a "hot cell" adjoins the pool at the end opposite the shield. Any of a number of metallurgical, chemical, or mechanical operations can be conducted on highly radio-

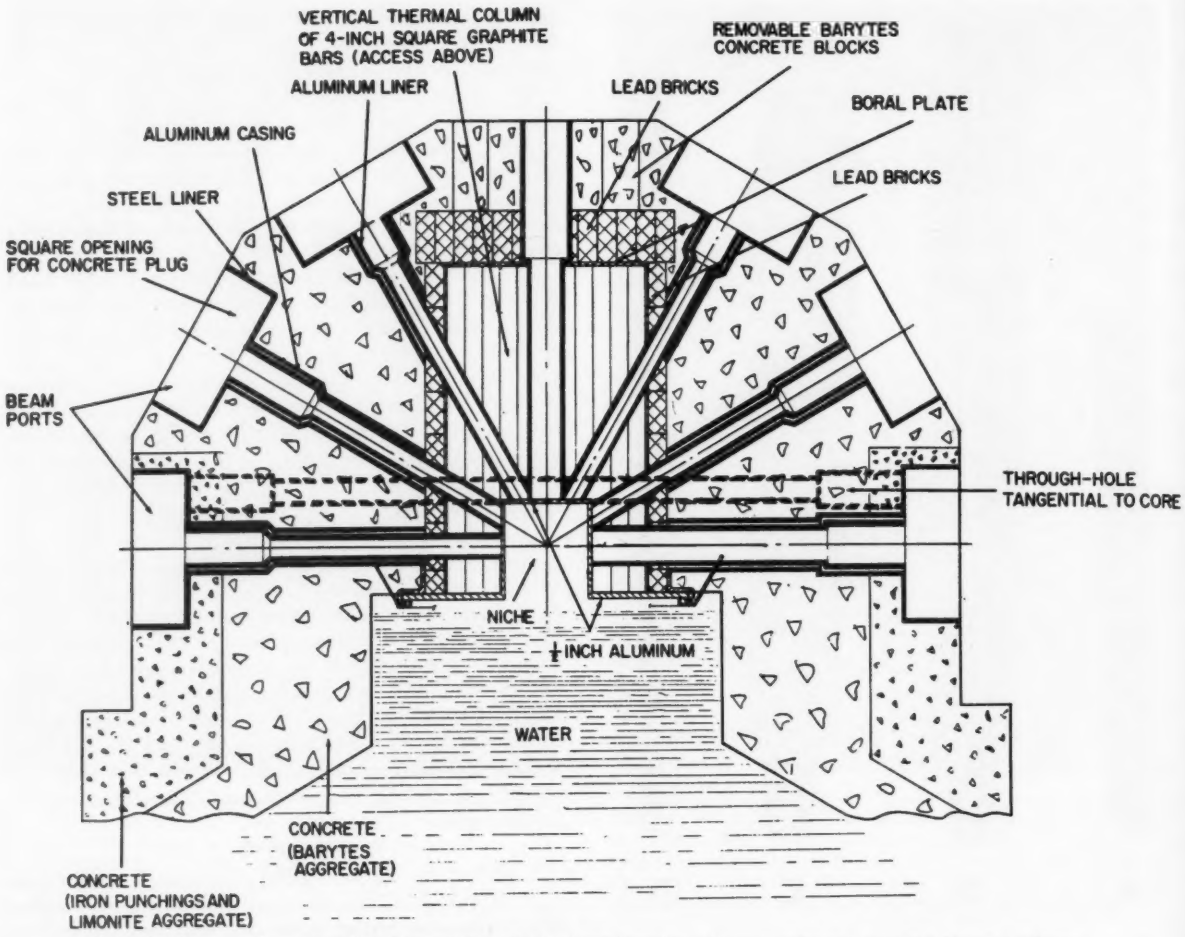

Figure 6. Horizontal cross section through the shield shows location of beam ports and graphite thermal column.

active specimens in the kilocurie range in this room by scientists working with special manipulators from an adjoining room. Objects made radioactive by suspending them close to the reactor core in the pool may be transferred directly into the hot cell through one of three underwater transfer chambers.

The cell is equipped with three special windows each three feet thick for direct viewing of operations. Each of these consists of two sheets of one-inch thick plate glass with the intervening space filled with a saturated solution of zinc bromide, a dense liquid with good optical properties and an excellent shield against radiation. In front of each window is a pair of master-slave hand manipulators, and the cell also has a heavy duty powered manipulator operated electrically from a console.

OTHER SPECIAL-PURPOSE LABORATORIES

The facility includes a shielded room approximately 12 x 30 ft used for measuring or "counting" the radioactivity in samples which have been exposed in the reactor. The walls and roof of this room are of two-foot thick concrete to reduce background radiation which would interfere with accurate measurements.

A laboratory for film development work also has been provided.

THE BUILDING

The reactor facility was constructed in a portion of an existing building on the grounds of the Laboratory to conserve space and reduce construction costs.

In the remote event that the interior of the building might be contaminated with radioactive materials, the entire building may be sealed. All of the exterior walls are sealed with a layer of aluminum foil installed behind the plaster, all exterior doors are a heavy, refrigerator type with gaskets, and all the ventilation ducts may be closed instantly by a central control unit. The roof is of concrete slab construction covered with tar.

The building has no exterior windows for reason of containment. A high light level and a variety of

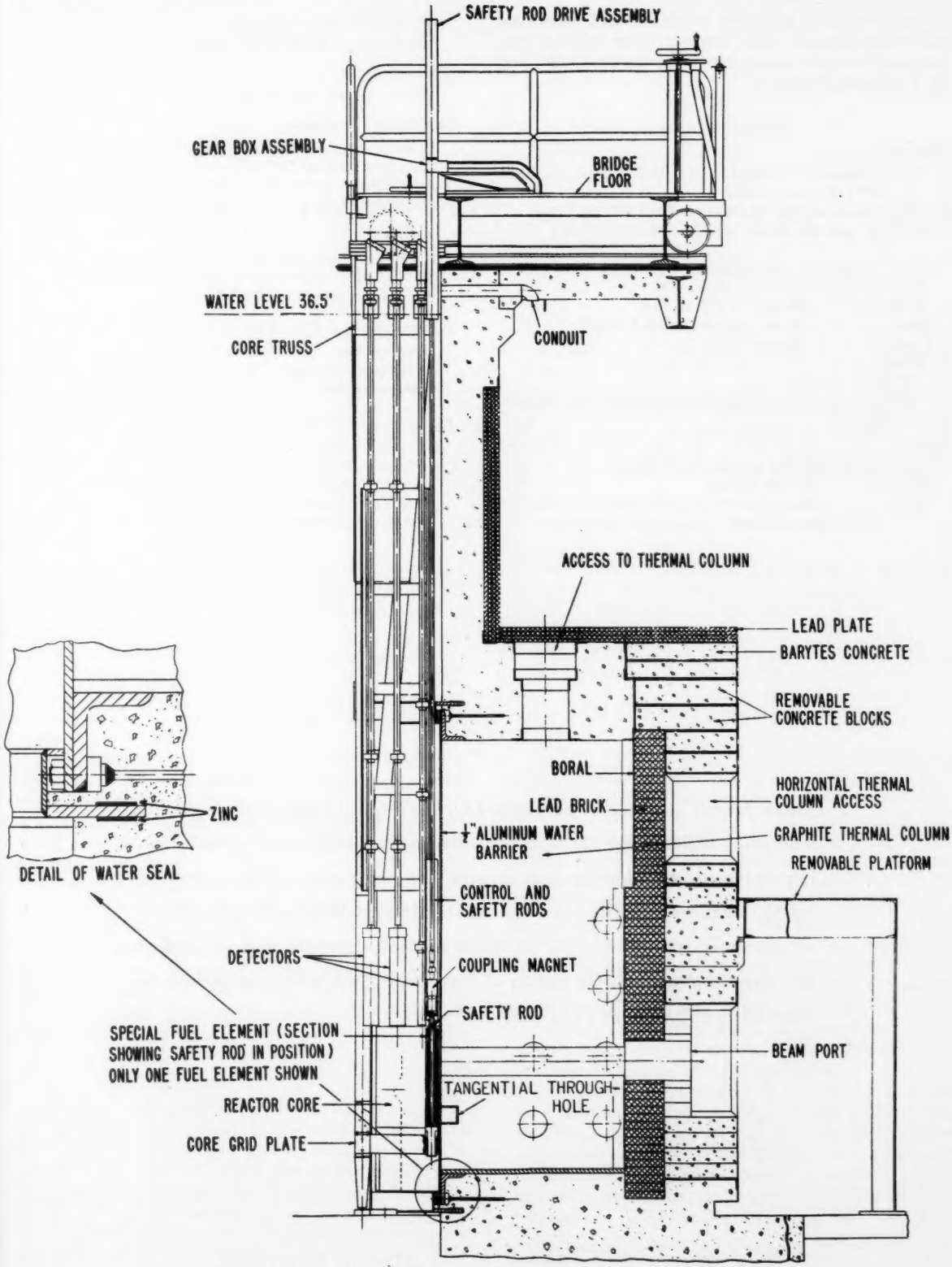

Figure 7. Vertical cross section through shield, reactor core and bridge.

colors have been provided in the building to reduce personnel fatigue. The interior color scheme was planned by color specialists from the Navy Bureau of Yards and Docks.

SPECIFICATIONS

Materials

Fuel—Uranium enriched to 90% U-235, as U-Al alloy, in TSF type assemblies
Critical mass in pool—approximately 3400 grams
Critical mass in shield position—approximately 2700 grams
Total inventory—5000 grams
Fuel cladding—0.020 in. aluminum
Moderator —Water—0.117 in. film
Reflector —Water, or water and graphite
Coolant —Water—0.117 in. film
Shielding
In pool—Water
In shield position—graphite, boral, lead, and barytes concrete

Pool

Dimensions—26 ft x 40 ft x 20½ ft deep
Capacity —150,000 gallons
Water —conductivity 0.15 micromhos; supplied by mixed bed ion exchange unit, output 30 gal/min

Core Dimensions

Up to 21 in. x 21 in. x 24 in. high

Cooling

Water, natural convection

Operating Conditions

Power rating—1000 KW (initial operation at 100 KW)
Heat flux max. at 100 KW—1000 BTU/hr ft^2
Average power density at 100 KW—1.1 KW/liter
Average specific power at 100 KW—30 KW/kg of U-235

Controls

Regulator—one stainless steel vertical rod
Safety/shim—three boron-lead vertical rods
Reactivity change at 100 KW—0.08

Neutron Flux at Core Surface at 100 KW

Average fast —3.5 x 10^{11} n/cm^2 sec
Average epithermal—5 x 10^{11} n/cm^2 sec
Maximum thermal —1.3 x 10^{12} n/cm^2 sec

Experimental Facilities

6 round beam ports, 6 in. diameter
1 rectangular beam port, 10 in. x 12 in.
1 square tangential through-hole, 4 in. x 4 in.
1 thermal column, 3½ ft x 4 ft x 9½ ft
2 pneumatic rabbits

Observations and studies conducted by the Woods Hole Oceanographic Institution indicate the existence of a thermally driven deep current flowing to the south under the Gulf Stream. The exploration of this current is being conducted by the use of an electronic signalling device encased in an aluminum pipe which can be made neutrally buoyant and tracked at the desired depth. Confirmation of this current will add substantially to knowledge of the ocean's circulation.

HOLMES F. CROUCH

SAFETY MEASURES FOR NUCLEAR SHIPS

THE AUTHOR

is a graduate of the U. S. Coast Guard Academy in 1940, served on various Coast Guard vessels during World War II, and later (for seven years) as a safety inspector of merchant ships. Subsequent thereto he has specialized in engineering research and technical writing in the electronic, nuclear, and guided missile fields. He holds a Master of Science Degree in Nuclear Engineering from the University of California. Mr. Crouch is presently employed as a nuclear engineer in the Research Division of the Marquardt Aircraft Co., Van Nuys, California.

According to various public releases, there are either under construction or on order, a total of 19 Navy nuclear ships* . . . and two Merchant nuclear ships. Completion dates are anticipated in the early 1960's. By that time, large-fleet philosophies of safety will emerge from the nuclear concepts of today. More nuclear ships mean more nuclear reactors, more humans . . . and more likelihood of accidents.

Should there ever be a major nuclear ship accident involving the uncontrolled release of radiocontaminants—in harbors or offshore, in this country or abroad—there would follow very stringent safety regulation indeed. The result could retrograde nuclear ship progress as much as 10 years. The severity of restraint (nationally and internationally) would be felt equally by naval men-of-war or merchant ships-of-trade.

Rather than waiting to impose safety measures as the need arises, it would appear advantageous to commence some of the broad technical planning now. As a guide toward this end, the following discussion is presented.

INITIAL PLANT LAYOUT

Any new ship propulsion plant requires systematic layout in terms of the purpose it is to serve and the hazards it is likely to present. Nuclear power is a prime example. To utilize this power safely, it is desirable to divide the overall plant into its radioactive and non-radioactive portions. In other words, a two-plant layout would be involved, namely: one for the reactor and one for the turbines. This would isolate the turbine plant (steam or gas) from the reactor and thereby would eliminate the possibility of radioactive contamination in the turbines and associated auxiliaries. Thus, conventional engine-room operating and maintenance procedures could be continued without the necessity for special precautions. This isolate-the-hazard technique is a well established principle in shipboard fire-fighting and damage control.

Within the reactor portion of the propulsion plant, several radiological safety features might be considered. Foremost is the matter of biological shielding. Here, it is possible to strategically zone the levels of tolerable radiation so that routine maintenance of reactor auxiliaries and emergency access to reactor controls could be achieved. For this purpose, special radiation-tight quick-opening doors would be required. The thickness of doors would vary in accordance with the time duration of the radiation zones, for example, two-hour zones, half-hour zones, emergency zones, etc. In addition to the practical effect of such zone-shielding, psychological advantages would accrue. Reactor personnel would become expertly cognizant of the acceptable standards of radiation safety.

The safe radiation exposure that can be tolerated by a human throughout his working lifetime (i.e., 40 years) is 600 roentgen.* This is the tolerance established by the International Commission on Radiological Protection. Based on a 40-hr. week, this tolerance is the accumulation equivalent of 7.5 mr./hr. . . . every 8 hrs. of every day. Or, if ex-

* See p. R7, March, 1957 issue of *Nucleonics* Magazine (McGraw-Hill).

* The unit of biological radiation dose is the roentgen (r). The roentgen is a rather large unit, so the milliroentgen ($1\ mr = 10^{-3} r$) is commonly used. The integrated product of the dose rate (r/hr. or mr/hr.) and the exposure time (sec., min., or hr.) gives the total dose received.

perienced in a 4-hr. watch, the daily tolerance is equivalent physically to a dose rate of 8 r/hr. for one minute. An accumulation of three times this rate (i.e., ~ 25 r) would produce no detectable clinical effects.* Hence, higher-than-standard radiation levels can be permitted for short periods of time . . . with safety. It would be desirable to take advantage of this fact.

A major radiological safety consideration is that of "core containment." In the improbable event of reactor meltdown, there would be no explosion, noise, or fire of any kind.† It would be detected primarily by radiation instruments and a large instantaneous temperature rise. The reactor thereafter automatically would shut down on its own, accompanied by the release of large volumes of radioactive gases and molten fission products. To contain these contaminants, a special pressure vessel (safety tank) around the core would be required. This would dictate that automatic quick-closing valves shut off the normal coolant flow and switch to an auxiliary cooling system to dissipate the heat of the molten core.

FUEL ELEMENT DESIGN

The most probable mishap in a reactor plant is the failure of one or more of its fuel elements. This is analogous to the development of leaks, ruptures, and bowed tubes in a conventional water tube boiler. The consequences are not major but they are an operating inevitability.

There are somewhere between 100 and 1000 fuel elements in a reactor, depending on its design and power rating. These elements consist of nuclear fuel in the form of thin plates, pins, rods, pellets, etc. A coolant material (i.e., water, liquid metal, or gas) flows adjacent to each fuel element to remove the fission heat generated therein. Fuel elements are designed to very close dimensions, so that the occurrence of any hot spots in the fuel material, or any obstruction of coolant passages, readily causes a failure. Many failures are the result of the capricious nature of uranium itself.

Between any ambient temperature and its melting point (2070° F), uranium undergoes three different crystalline changes, designated as alpha, beta, and gamma. The stability range of alpha-uranium extends to about 1225° F. Thereafter, it goes through an alpha-to-beta transition and its metallic crystals change abruptly from an orthorhombic structure (three unequal axes) to a tetragonal structure (two unequal axes). In the process, one cell dimension increases almost four-fold, a second increases about 10%, and a third dimension disappears. The accompanying volumetric distortion is extensive, and the beta crystals are hard and brittle. The result: cracks, ruptures, and bows develop in the fuel elements. If the fuel is alloyed with other metals, phase transition problems can be improved somewhat. Nevertheless, for each type of nuclear fuel there exists a maximum temperature to which it can be used safely. Under the circumstances, it would be sound practice to establish regulatory temperature limits for nuclear fuels . . . analogous to maximum working pressures on conventional boilers.

For each gram of nuclear fuel that is fissioned, there results an equal weight of highly radioactive fission products. For obvious reasons, these fission products must not emerge into the coolant stream where they can be carried out of the reactor core. To prevent this, the fuel elements are cladded in a container material, comparable in principle to core containment mentioned previously (except on a much smaller physical scale). Consequently, safety standards and specifications for cladding materials, including fabrication and leak testing procedures, could be established.

Because of the great number of fuel elements in a reactor, they usually are grouped into bundles. For nuclear plants ashore, these bundles are lowered into place with no undue concern for their in-service disarrangement. On shipboard, however, new hazards are introduced by normal vibrations and poundings at sea. A nuclear ship rising up on one wave and slamming down on the next would only too readily loosen its fuel elements. The subsequent disarrangement would set up restrictions to the flow of coolant, thus producing rapid failures. To prevent this, a positive locking arrangement could be provided. Not to be overlooked, however, is a means of quick unlocking when it comes time to remove the fuel elements for refueling.

STARTUP AND CONTROL

Once a reactor has been safely fueled, safety attention turns to the longer term aspects of reactor startup and its operational control. This is done by means of mechanical rods which move in and out of the reactor core to absorb those neutrons which are generated in excess of the power level desired. Safety problems arise from the fact that all fuel for the anticipated cycle of the reactor is "built in," and therefore control rods control only the *excess* fuel in the core.

The effectiveness of control rods in doing their job is contingent upon numerous factors, namely: (a) status of fuel depletion, (b) position of insertion in the core, (c) mutual shadowing from other control rods, (d) status of absorber depletion, and (e) the actuating servomechanisms used. All of these factors introduce non-linearities into the control rods which means that one is never sure from one control rod position to the next, just what the reactor response will be. On shipboard particularly, this means that manual control is out of the question. To offset the risks involved, foolproof, fail-safe, and absolutely reliable automatic control systems must be devised. Detailed safety standards and specifications could be promulgated toward this end.

* 25 r compares with the radiation dose one gets from a dental X-ray or fluoroscopic examination.

† See "A Letter on EBR-1 Fuel Meltdown" by W. H. Zinn (Director of Argonne National Laboratory) in June, 1956 issue of *Nucleonics* magazine.

The heat power produced by a reactor is directly proportional to the average thermal neutron flux in its core. The rate of change of this flux level is a very delicate phenomenon. Mathematically, it follows the relationship

$$\phi_t = \phi_o e^{-\frac{t}{T}}$$

where ϕ_t is the flux at time t, ϕ_o is the flux at time zero, and T is the reactor period (i.e., the time for the reactor to change its flux level by a factor e = 2.716). If T, for example, were set at 15 sec.* the reactor could start up from a zero power level at criticality (say, $\phi_o = 1$) and reach full power (say, $\phi_t = 10^{14}$) in about 8 minutes! This is too fast for structural safety. The resulting thermal stresses would warp or crack the containment vessel, burn out the fuel elements, and do damage to thermocouples and other fittings inside the core. Nor would the coolant be able to remove the fission heat fast enough. Obviously, a program of reactor preheating and gradual warmup would be needed, much the same as carried out in a conventional boiler plant.

Once a reactor has been started up from its clean-cold condition, there would be no need to shut it down to zero flux each time a ship arrived in port. In fact, there would be disadvantages in doing so. Foremost, there is the phenomenon of xenon poison buildup. Xenon, one of the many after-products of fission, acts as a "poison" because its neutron absorptivity is 1000 times greater (per atom) than that of the control rods proper.† After shutdown, this poison builds up to peak values, due to the natural decay of fission products. The consequence is that the reactor cannot be started up again with the same control rod positions that prevailed at time of shutdown. Extra rod withdrawal to override the poison is required. Once overridden, the poison burns out quickly and the control rods must be re-regulated with precision . . . to avert reactor runaway.

Shutting a reactor down completely imposes unnecessary risk. Instead, the reactor flux need only be reduced to 10^{-4} (one ten-thousandth) of its full power, at which level no useful propulsion power could be generated. The advantage is that the residual "simmer flux" (i.e., 10^{10} if 10^{14} were full power) would burn out the xenon poison and keep the reactor warm and ready, so that frequent safe restartups could be made.

OVERBOARD WASTE DISPOSAL

Once a reactor plant has achieved normal operation, there would be those unending daily tasks of routine maintenance, cleanup, repair, overhaul, etc. Much of this work would take place within various zones of radiation shielding and would involve the collection and accumulation of low-level radioactive wastes. There would be those inevitable leaks in the reactor coolant piping, flanges, fittings, and joints. Radioactive particulates such as corrosion and dust would appear at pumps, heat exchangers, coolers, actuators, etc. Filters in ventilating, cooling, lube oil and other auxiliary systems would collect radioactive residues and would require changing. Tools, gloves, and cleaning rags would become contaminated. All of these radioactive accumulations (consisting of solids, liquids, and gases) are perfectly normal operating occurrences; they happen every day at such atomic plants as Hanford, Oak Ridge, Chalk River (Canada), etc. They do *not* pose any major hazard.

However, there is one basic precaution: radioactive wastes and residues must not be dumped or pumped overboard at random. Instead, a systematic arrangement of collection tanks would be required aboard ship. Dry wastes would be collected in one tank, liquid wastes in another, and gaseous wastes in still another. There would need to be some means of concentrating and decontaminating these wastes, and means for holding them in storage (behind shielding) until they could be disposed of safely at sea.

The responsibility for disposal of radioactive wastes would rest with the Commanding Officer (if a Navy ship) or Master (if a Merchant ship). This responsibility would be analogous to that under the Oil Pollution Laws whereby the ship must be beyond a minimum specified distance offshore before pumping slop oil overboard. In the case of radioactive wastes, a suggested minimum distance is 50 miles. Every disposal event would be recorded in the ship's official log.

In preparation for disposal, special equipment would be required. Solid wastes would be collected, compacted and permanently sealed in concrete drums with positive locking devices. Liquid wastes would be discharged through underwater high pressure pumps and valves discharging aft (to minimize radioactive contact with the ship's hull). Gaseous wastes would be discharged from the highest point possible—preferably the masthead. A steam ejector or other exhauster system would be required to purge the mastlines of all radioactive gases, and to jet the exhaust stream clear of the ship. This procedure would be comparable to blowing boiler tubes on an oil-fired ship. All disposal equipment falls within the province of safety measures to protect the crew and the public against the non-vigilant release of radio-contaminants.

RADIATION MONITORING

As further protection to the ship's crew and to the public, including the reactor plant itself, radiation monitoring equipment would be required. The purpose of this equipment would be to immediately detect radiation leaks, measure excess exposure tolerances, and report the same either in the form of an audible alarm or permanent record, or both. The state of radiation monitoring art is so well advanced

* A safe value for control by delayed neutrons.

† Cadmium is frequently used as a control rod absorber material. Its thermal neutron (microscopic) cross section is 3,300 barns compared to the cross section of 3,200,000 barns for xenon.

ashore that marine safety effort need only be devoted to modification and adaptation of existing instrumentation to shipboard environments.

Those instruments monitoring the reactor plant would provide information primarily to the engine-room and reactor maintenance personnel. Radiation detector heads would be located to report fuel element failures and to report leaks in coolant piping, heat exchangers, biological shielding, etc. All detectors (i.e., those permanently installed) could be cabled to a central tell-tale panel and buzzer system in the engine-room, to call attention of on-watch personnel to the radiation circumstances at hand. This would be comparable to salinity indicators, high temperature and low-flow alarms now centralized in the engine-rooms of modern ships.

General monitoring equipment protecting the crew would be comparable in operation and function to conventional automatic fire detection and alarm systems aboard ship. In this case, the central control station could be on the navigating bridge. Detector heads would be located at key points throughout the ship—particularly in the ventilating, drinking water, and sanitary systems. Special locations might be considered where radiation could follow a structural frame, fire main, or hull plating and then emerge into crew areas. The same radiation tolerances used ashore could be put into effect on shipboard. As an example, the acceptable drinking water tolerance for beta and gamma activity is 6×10^{-6} μc/cc; the corresponding tolerance for breathing air is 6×10^{-10} μc/cc.* In other words, a mariner could safely drink about 10,000 time more radioactivity than that which he could breathe!

Radiation detectors also would be located in all effluent systems that discharged continuously into the air or water surrounding a nuclear ship. In this case, a permanent record of all monitor readings would be kept as legal evidence in the event of third-party claims of radiation damage. Undoubtedly, very detailed administrative procedures would be worked out for this purpose.

EMERGENCY SHUTDOWN

Under the safest possible conditions, there may arise—sooner or later—some unforeseen circumstance to require the emergency shutdown of a ship's reactor. There may be collision between a nuclear ship and a non-nuclear one; heavy fog and faulty navigation may cause grounding; control rods may jam or maximum temperature control devices may fail; or there may be torpedoing, bombing, or other forms of enemy action. These are emergency situations requiring instantaneous shutdown of the reactor to safeguard it against the potential release of large quantities of radio-contaminants. These situations would fall into two classifications of safety, namely: (a) scram control and (b) abandon ship.

Scram control involves the overriding of all automatic control features by inserting large-rod absorptivities into the reactor core to sharply curtail its neutron flux. This "scram" (as it is called) induces immediate reduction of the flux level to zero, though reactor heat continues to be generated for some time afterward.* From the safety viewpoint, the scram actuator mechanisms constitute dominant concern. They must be absolutely reliable under all conditions. Present actuators consist of mechanical tripping devices, gravity magnetic releases, spring loaded drives, powered piston mechanisms, etc. Early effort is needed to standardize on a universal type of actuator . . . with a specified maximum time-delay of response. A suggested response time is *less than* 50 milliseconds.†

To produce reactor scram, "scram buttons" could be located on the navigating bridge and in the engine-room, and could be tied in to the General Alarm. In addition, scram control automatically could sound a special ship's danger signal (for radiation danger!) to warn other ships in the vicinity to stand clear. Simultaneously, if the event occurred in a harbor, the radiation danger signal would alert fireboats, tugs and other emergency craft to proceed to the scene and prepare to tow the nuclear ship out to sea, or tow it to remote anchorage.

The occasions for abandoning a nuclear ship would be identical with those for any conventional ship. The ship may be in a sinking condition at sea, it may be breaking in two on coastal rocks, or it may be gutted by explosion and fire in a safe harbor. Should the order to "Abandon Ship!" be given, there would be one remaining nuclear safety measure. It would be necessary to completely poison the reactor by the release of *great quantities* of neutron absorbers through special tubes, vials or other flood-release devices. This destructive action would assure that the reactor would never again generate new fission products. This assumes, of course, that the then-existing radio-contaminants would be permanently contained within the core safety tank (mentioned earlier).

CONCLUSION

This discussion by no means covers a complete program of safety measures for nuclear ships. Many facets of reactor core design, fuel element fabrication, automatic control devices, radiation shielding zones, etc., remain to be defined in a marine environment before complete safety coverage can be previewed. Nevertheless, there is sufficient technical information at hand to lay the foundation now for specific safety effort for large-fleet nuclear operations.

* 1 c/cc = one microcurie per cubic centimeter = 2.22×10^9 radioactive disintegrations per minute per liter sample of water or air. See paper No. 57-34, "Health Physics Instrumentation for a Power Reactor," G. H. Whipple, 2nd Nuclear Engineering and Science Conference, March, 1957, Philadelphia, Pa.

* The heat generated after reactor shutdown follows the relationship

$$P_t = 0.0315\, P_o t^{-0.2}$$

where P_t = heat power as a function of time t after shutdown; P_o = heat power prior to shutdown; t = time after shutdown in *seconds*. For example, 10 hrs. after reactor shutdown, a 100 MW reactor would continue to generate about 300 KW of heat.

† See paper No. 57-17: "The Development of Universal Control Drive Mechanisms for Nuclear Reactors"; G. Roland & C. Hinrichs; 2nd Nuclear Engineering and Science Conference, March, 1957, Philadelphia, Pa.

With but one exception, there already exists in conventional marine safety a precedent—a comparable analogy—on which to base all nuclear ship safety measures. The exception: There must be no *major* disaster (as in the past) to preface the need for a particular safety measure. Barring all-out atomic war, every minor accident to a nuclear ship —be it a naval or merchant ship—would be scrutinized with apprehension and alarm. Wherever it appears that similar accidents under less favorable circumstances could lead to the uncontrolled release of radioactivity, stringent regulation would follow. To avoid this, and at the same time to chart the proper balance between regulatory safety and nuclear progress, it would appear that an overall national nuclear ship safety program might be helpful.

BIBLIOGRAPHY

Textbooks

1. S. Glasstone, *Principles of Nuclear Reactor Engineering*, D. Van Nostrand Co., Inc., 1955.
2. D. H. Gurinsky and G. H. Dienes, *Nuclear Fuels*, D. Van Nostrand Co., Inc., 1956.
3. M. A. Schultz, *Control of Nuclear Reactors and Power Plants*, McGraw-Hill Book Co., Inc., 1955.
4. R. Stephenson, *Introduction to Nuclear Engineering*, McGraw-Hill Book Co., Inc., 1954.

Magazines

5. "How to Test a Nuclear Power Plant"—Special Report, *Nucleonics*, October, 1954.
6. "Engineering and Construction of Nuclear Power Plants" —Special Report, *Nucleonics*, June, 1955.
7. Jones and Witzke, "Some Operational Problems of the Nuclear Power Plant," Paper No. 57-24, 2nd Nuclear Engineering and Science Conference, March 1957.
8. Robb, Sampson, Stehn and Davidson, "Fission-Product Buildup in Long-Burning Thermal Reactors," *Nucleonics*, December, 1955.
9. Verkamp and Williams, "Testing Nuclear Plant Leaktightness," *Nucleonics*, June, 1956.

"THE MARINE ENGINEER & NAVAL ARCHITECT"

DESIGN AND APPLICATION OF MARINE FREE-PISTON GAS GENERATORS

ACKNOWLEDGEMENT

This is an abridged version of a paper read before the Institution of Naval Architects on 6 December 1956, as published in the February, 1957, edition of "The Marine Engineer and Naval Architect." The authors are M. A. Augustin-Normand, Jr., Managing Director of Chantiers et Ateliers Augustin Normand, and M. E. Barthalon, Chief of Free-Piston Engine Department, S.I.G.M.A.

THE reciprocating steam engine has left a memory with sea-going engineers which is difficult to eradicate. Its absence of maintenance and its flexibility in operation gave the engine-room staff a peace of mind which is now somewhat disturbed by more modern engines. Shipowners, however, could not continue to bear the high fuel costs of this engine, which has consequently given place to the steam turbine and diesel engine. The dilemma posed by comparison of the two latter solutions, the fuel cost and the maintenance cost, has not been solved, however, since shipowners often still hesitate between the two types of propulsion equipment for one and the same program.

In terms of simplicity, free-piston gas generators approach the reciprocating steam engine, and the companies which have developed them have thought that after some years of development they would be able to satisfy the engine room staff, the engineers, and the shipowners.

The first GS-34 gas generators to leave the S.I.G.M.A. factories were delivered to Electricite de France in June 1951. The first naval vessel fitted with gas generators and gas turbines put to sea in April 1952 and during subsequent months twenty identical minesweepers followed suit. The first two similarly-equipped merchant vessels, *Cantenac* and *Merignac*, went into service in February and August 1954, respectively. They have been at sea practically without interruption since that time. Stationary and locomotive applications have followed a parallel development and a total of 200,000 h.p. is in service or under construction.

Shipbuilders, in common with shipowners, once having decided the broad lines of a project, usually seek propulsion equipment which will provide the greatest available space and weight for cargo and passenger accommodation. We will therefore start by comparing the free-piston gas generator and gas turbine propulsion unit with other methods of propulsion at present used. A parallel study is made of the overall space occupied by the engine installations for a range from 1,000 to 8,000 b.h.p. comprising.—

(1) An in-line engine, 530 mm. bore, 800 mm. stroke, running at 214 r.p.m. with a number of cylinders varying between 4 for 3,240 b.h.p. and 10 for 8,100 b.h.p.

(2) A high-speed V-engine, 400 mm. bore, 460 stroke, running at 425 r.p.m., supercharged to 60 per cent with number of cylinders varying from 10 for 2,500 b.h.p. to 24 for 6,000 b.h.p., with reduction gear reducing the speed to 300 r.p.m.

(3) The same high-speed V-engine, 400 mm. bore, 460 mm. stroke, running at 520 r.p.m., supercharged to 75 per cent, with number of cylinders varying from 10 to 3,330 b.h.p. to 24 for 8,000 b.h.p., with reduction gear reducing the speed to 300 r.p.m.

(4) A propulsion set comprising a reduction gear, a gas turbine, and a number of free-piston gas generators varying from 1 for 1,000 h.p. to 8 for 8,000 b.h.p. The volumes also take into account the gas piping between gas generators and turbines.

We have collected together the overall volumes occupied by the various solutions and have shown them in the form of curves (Fig. 1) as a function of power developed. It should be observed that total volumes (with engine auxiliaries) are given. The actual space of an engine compartment for free-piston gas generators and gas turbines is further reduced in relation to that occupied by a diesel engine because the connections between gas generators and turbines are

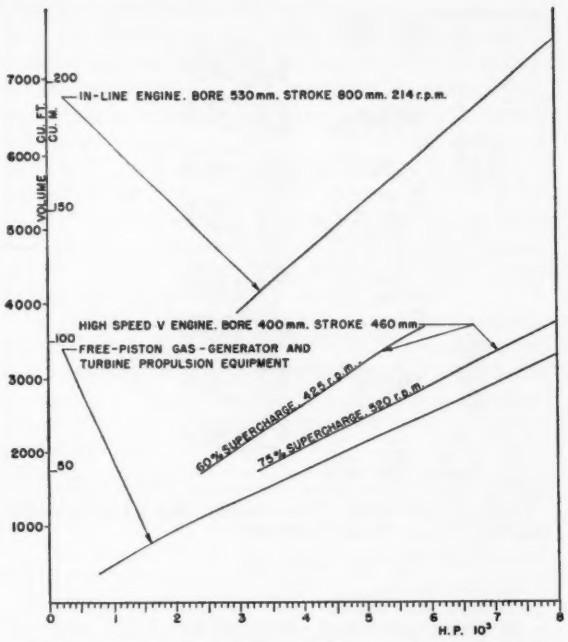

Figure 1. Space Requirements of Different Types of Propulsion Equipment.

pneumatic only and allow complete flexibility of layout in the engine compartment. Only the reduction gear unit must conform to the shaft. This unit is quite small (6 to 8 cu. m. for 8,000 h.p.). It can easily be accommodated in the extreme stern of a vessel, thus appreciably reducing the length of the propeller shaft.

The pipes between the gas generators and the turbines can easily be run along the overhead of the compartment so that they do not interfere with the space available for the ship's engineers. The space necessary for dismantling and for inspection are combined, due to the horizontal position of the gas generator cylinder in a free-piston unit. In the case of diesel engines, additional height is required for lifting pistons and rods out of the cylinder block. The low height of free-piston gas generator and turbine sets makes it possible to utilize for accommodation, for example, the space occupied by the engine casing necessary for the majority of diesel engines.

WEIGHT

Curves setting out the weight per h.p. in relation to the power, for the same engines are shown in Fig. 2. These employ, as a reference unit, the GS-34 gas generator, the type of construction of which is similar to that of slow-speed diesel engines. Much more compact gas generators are in the course of development.

The small weight and flexibility of installation of the gas generators, and the small space occupied by the turbo-reduction gear unit, make it possible in all cases to locate the engine room right aft, in order to free completely the center of the vessel, which is thus available for the cargo or equipment. For very specialized vessels (mail boats, ferries) the low height of the engine compartment renders it possible to provide particularly well-adapted installations.

TURBINES

The space and cost of the turbines vary approximately as the square root of their power. The single turbine is therefore the least costly. The rotational speed of a turbine diminishes as the power increases, and the reduction gear ratio to be introduced between the turbines and the propeller shaft is lower.

The use of two turbines makes it possible to divide the propulsion unit into two parts and to operate on half power with the optimum rating of the gas generators. The reduction gear is symmetrical and comprises two primary shafts for one secondary shaft, the classic arrangement on steam turbine installations. The intake elements have smaller dimensions but this would also be the case for a single turbine with several intakes, a solution commonly employed on turbo-blowers for supercharging.

Reliability is improved, but this factor is of little account when the 16,000 running hours of the Metlaoui power station turbine, the 8,000 running hours and the 6,000 running hours of the turbines in *Cantenac* and *Merignac*, without any trouble, are borne in mind. Turbines supplied with gas from gas generators are at least as reliable as steam turbines which are subjected to temperatures of the same order and to pressure of a much higher level.

The design of the gas piping gives rise to the classic problems of expansion. Their conception can have an important influence on the cost of the installation and its flexibility of operation.

The essential cooling and lubricating oil systems are similar to those for a slow-speed diesel. The compressed air system, on the other hand, is appreciably smaller. As with large diesel engines, it is more rational to drive the auxiliaries by means of electric motors, which consume a small percentage of the

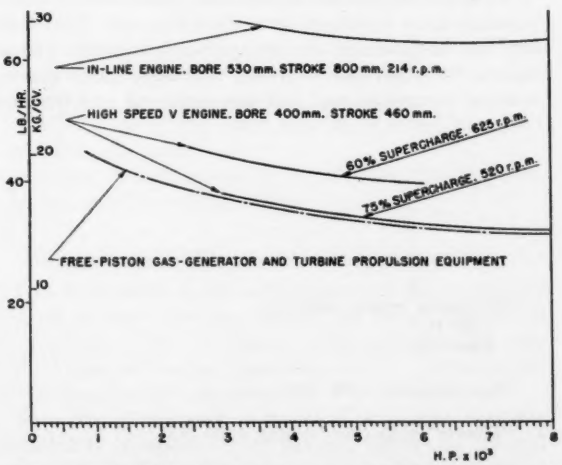

Figure 2. Weight per Horse-power of Different Types of Propulsion Equipment.

total normally provided and afford great flexibility of operation.

Application to an oil tanker of 20,000 tons and 8,000 h.p. or to a cargo vessel of 7,000 tons and 7,000 h.p. yields the following arrangement. For reasons of good distribution and operation two groups of pumps are used, each supplying four gas generators and each consuming 80 kW. The arrangement of the engine compartment is shown in Fig. 3; eight free-piston gas generators supply a single gas manifold. From this manifold, two supply lines feed a turbine with divided admission, which is connected to the propeller shaft through a reduction gear.

The same manifold supplies the 300 kW turbo-dynamos, two in the case of the cargo vessel and three for the tanker specified. With this installation the gas generators provide for propulsion, and for electricity generation from a single turbo-dynamo set, when at sea. In harbor, when the main turbine is not running, it is sufficient to leave one gas generator running in order to provide the power necessary for the cargo-handling load. A 100 kW diesel generator set provides the current for initial starting of one of the two groups of pumps, in addition to ship lighting in the case of prolonged immobilization. One problem still remains unsolved at present, namely combining the lubricating systems of the gas generators and of the turbo-reduction gear unit, which could provide a saving in weight of the order of 8 to 10 tons in the case of a propulsion unit of 6,000 to 8,000 h.p.

The service requirements of the ship will very largely influence the design of the engine unit. A cargo ship will require continuous operation on full power, a coasting vessel many hours of maneuvering, while a warship will require low cruising power and very high combat power. With free-piston engines it has therefore been necessary to obtain not only correct consumption on full load, but an acceptable consumption on partial loads, which, as is known, is difficult with classic gas turbines.

As in all propulsion equipment, problems of astern running have required some development. Very wide use has been made of arrangements already proved over a long period on steam turbines, since the operating temperatures and pressures of gas turbines

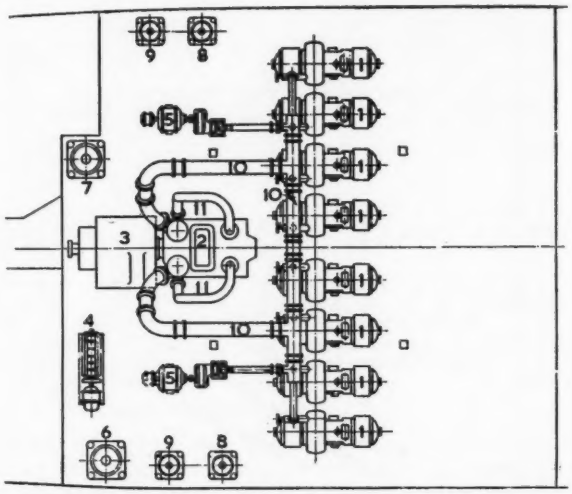

Figure 3. Free-piston Gas-generator and Turbine-propulsion Equipment; Power, 8,000 H.P.

(1) Free-piston gas-generators.
(2) Gas turbine.
(3) Reduction gear.
(4) Electric-generating set of 100 kW.
(5) Turbo-dynamo of 300 kW.
(6) Turbine and reduction-gear oil pump.
(7) Turbine and reduction-gear stand-by oil pump.
(8) Duplex pump, fresh-water and sea-water.
(9) Gas-generator oil pump.
(10) Gas manifold.
(11) Gas pipe for astern operation.

fed by free-piston gas generators are lower than, or equal to, those of medium-pressure steam turbines.

FUEL CONSUMPTION

Table I sets out the results successively obtained. These results have already been improved on a test engine by detail modification of the injection system and of the piston crown, bringing about a reduction in consumption of approximately 5 per cent.

The figures obtained are no doubt slightly higher than the figures guaranteed for the best existing marine diesel engines, but they are remarkably constant within the limit of our experience (three years) during the life of the ship. In addition fuel consumption is only one of the factors in the operational balance

TABLE I

	Consumption, turbine shaft		Gear efficiency	Turbine efficiency (including rev. drive)
Cherbourg power station:—			Per cent.	Per cent.
4,000 H.P.	287 g./kWh.	0.633 lb/kWh	—	—
8,000 H.P.	248 g./kWh.	0.547 lb/kWh	—	88 (without rev. drive)
Minesweepers, 1,000 H.P.	193 g./ch.h. (gas oil).	0.430 lb/H.P.-hr.	96	84
"Liberty" ship (test bench), 3,000 H.P.	190 g./ch.hr. (Bunker C)	0.423 lb/H.P.-hr.	96	86
Marine set (projected), 8,000 H.P.	183 g./ch.hr. (gas oil)	0.418 lb/H.P.-hr.	96	86

sheet as demonstrated by the numerous orders for steam turbine sets despite their high consumption.

In the present state of the technique, the utilization of heavy fuel oils is a necessity. It is therefore interesting to observe that the combustion of heavy fuel oil with a viscosity of up to 3,000 sec. Redwood I at 100° F has required absolutely no modification to the GS-34 gas generator. This is well explained by the very high degree of supercharge of the engine, the complete separation of the diesel cylinder from the rest of the engine, lubrication by total loss, and the absence of valves in the diesel cylinder.

Parallel with this, it should be observed that very satisfactory operation of the injection equipment has been obtained with a moderately heated oil having a viscosity of 150-180 sec. Redwood I. Up to the present, cooling of the injectors has not been necessary for good reliability.

Various possibilities exist for reducing consumption at partial loads, namely:—Improvement of the consumption curve of the gas generator itself, reduction in the number of gas generators in service and adaptation of the turbine design.

The two first subjects will be touched on below. The third will be dealt with in the paragraph dealing with turbines.

The specific consumption of a gas generator is essentially a function of the gas delivery pressure. It increases appreciably as soon as this falls below 1.5 kg/cm.^{2}. In fact, below one-third load, since the gas flow from the gas generator cannot be matched to the turbine, it is necessary to blow off to atmosphere part of the gas generator and the consumption increases rapidly.

RECIRCULATION

An attempt has therefore been made to reduce the gas generator output in this zone by applying the principle of recirculation of hot compressed air to the compressor intake (Fig. 4)

Heating the intake air permits operation with very low engine compression. It is thus possible to move the inner dead point further from the center-line, increasing the compressor clearance volume and reducing its delivery per stroke, and also to reduce the cushion pressure, and thus the speed of oscillation. As a result there is a double diminution in the gas generator output which can then follow exactly the turbine mass flow curve down to an admission pressure almost to zero.

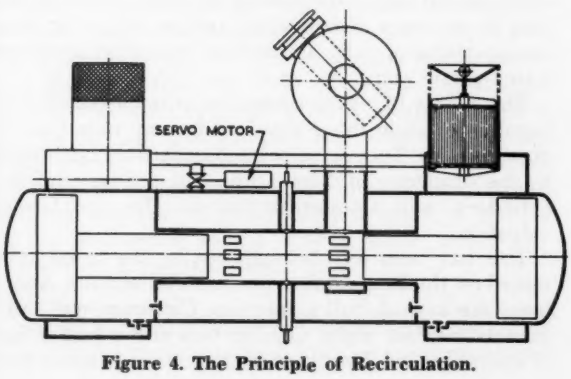

Figure 4. The Principle of Recirculation.

The coasters *Cantenac* and *Merignac* were fitted with this arrangement, which was necessary in their case in view of their large proportion of maneuvering time.

All conditions of cruising and maneuvering from stop up to full speed are permissible without any discontinuity, a feature particularly important in certain circumstances such as convoy operation, minesweeping and leaving harbor, when ships with free-piston engines provide a flexibility similar to that of ships with electric transmission.

Various solutions permit the exploitation of this feature. The first used exclusively so far on free-piston ships, consists in fitting the turbine with astern blading, and providing between the gas generator or generators one or more reversing valves, making it possible to vary the proportion of gas admitted to the ahead turbine and to the astern turbine. Control of the reversing valve and the fuel rack is carried out by means of a hydraulic circuit with two branches controlling, on the one hand the fuel rack for the range of power above one-third load, and on the other hand the reversing valve for the range of power below one-third load.

This system gave rise to a number of points for development. The oil pressure controller operated by the hand wheel was fed in parallel with the reversing valve and the piston cooling arrangements from a common oil pump. During reversing the sudden oil demand of the valve servo-motor resulted in a general reduction in the oil pressure, and consequently in a slowness in reaction of the whole arrangement.

These difficulties were resolved by fitting a slide valve regulator feeding first the maneuvering control, and then the reversing valve, and finally the piston cooling arrangements.

The reversing valve itself gave rise to the following points:—

Compensation of expansion which had been causing variations in the position of the valve according to the temperature.

Alteration of the valve profile in order to obtain a broad stop zone.

Detail modifications of the servo-motor in order to reduce the response time.

STABILITY OF OPERATION OF THE GAS GENERATOR

The operation of the arrangements for reversing and for power variation mentioned above, results in a variation in the discharge area available for the exhaust gas of the gas generator and in a variation of the fuel rack at the same time.

This has given rise to several problems relating to stability of operation of the gas generator. It will be appreciated that the piston stroke has maximum limits corresponding to contact with the cushion head

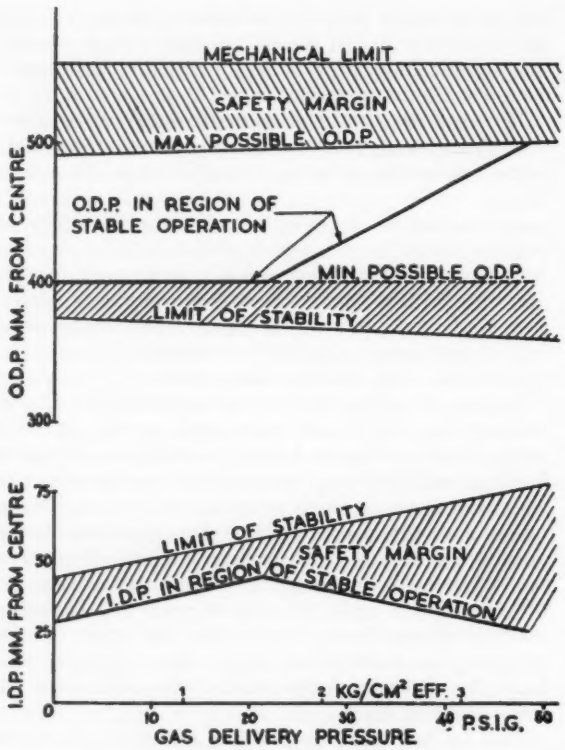

Figure 5. Limit of Stability.

or contact between the pistons, and minimum limits corresponding to the outer dead point allowing adequate scavenging, or to the engine compression being adequate for combustion. Fig. 5 gives an indication of the limits between which the inner dead point and the outer dead point must vary in order to avoid the gas generator stopping.

When the load rises rapidly the discharge area diminishes suddenly and the fuel rack increases immediately. It is then necessary to charge the cushion quickly in order not to exceed the outer limit. Conversely, during a reduction in load, the cushion must discharge sufficiently quickly for the outer dead point not to fall below the minimum value allowing adequate scavenging.

The problem is more complicated when reversal of the drive or a drop in load is followed immediately by an increase in the load. Recourse was had at first to some delay devices between the maneuvering control and the receiving units. In this way a drop in the operating pressure to too low a value is avoided when reversing. Later the flow rate and the response time of the stabilizer (the unit controlling the quantity of air in the cushion) were improved, thus making it possible to avoid stopping the gas generator when reversing without having recourse to a delay device.

TURBINE DESIGN

One or two astern stages are mounted on the same shaft as the ahead stages. The two half turbines have a common exhaust at the center. The windage of the astern stages, however, gives rise to a problem more difficult to solve than in the case of steam turbines, where a vacuum is produced in the astern casing.

Since the density of the gas is much greater, large losses occur proportional to the mass of fluid set in motion. However, numerous tests have made it possible to reduce these windage losses in the proportion of six to one in the case of marine turbines of 1,000 h.p. This was made possible by investigation into the variation of windage losses as a function of the speed of rotation, the dimensions of the discs and blades, the form of these blades, the conditions in the space surrounding the wheel, and the interactions between the gases leaving the ahead blading and the astern blading as the result of costly tests.

The subdivision in height of the astern stages and the adoption of fixed or movable masks explains the overall efficiencies indicated above. It will be observed with interest that in the particular case of the 1,000 h.p. turbine with fixed masks the windage losses represent approximately 2.5 per cent of the power involved. When using a movable mask (Liberty ship) these windage losses are less than 1.5 per cent.

ADAPTATION TO PARTIAL LOADS

With the methods of control described above, when the load diminishes the available pressure drop of the gas diminishes with the speed of rotation. Under these conditions the mean C/U ratio of the blading varies relatively little and the efficiency remains good over a large range of power. The efficiency of the turbine/reduction gear unit varies by only ten points between one-third load and full load. The efficiency of the gas generator, on the other hand, varies fairly quickly, as soon as the working pressure falls below 1.5 kg./cm.^{2}. It is therefore important, if it is desired to maintain a high efficiency at partial load, to have a smaller number of gas generators feeding a smaller turbine nozzle area at a gas delivery pressure similar to the full load pressure. Use can be made of the three classic systems on steam turbines:—Separation of first stage admission into sectors, use of two turbines, one for cruising, and separate admission before the third stage.

It is of interest to draw up a list of the difficulties encountered and subsequently eliminated during the first three years of operation, before observing how the problems of daily and annual operation occur on a free-piston ship.

The points of development have not exceeded in number or scale those required by any new type of diesel engine. They have been considerably facilitated by the simplicity of dismantling, independence of the cylinders, and standardization on the one GS-34 cylinder.

This has been well brought out by the results obtained on the first ships in commercial service. Apart from the annual hull inspection, *Cantenac* was only immobilized for eight days in two and a half years of operation and *Merignac* for four days in two years

of operation. The remainder of the maintenance was carried out during normal periods in ports. The main problems were as follows: —

Wear

Scattered cases of wear and sometimes of seizure were observed on the compressor of the first machines. These faults have been completely eliminated since June, 1954, by an appropriate design of the compressor piston rings. At first the engine piston rings had a life not exceeding 500 hours. Several periods of operation exceeding 2,500 hours without inspection of the rings were subsequently obtained in 1955 and 1956. The improvement related both to the material and the design of the rings, together with the oil used.

High oil consumption

Oil-tightness of the glands on the synchronizing rods and on the piston cooling oil tubes were difficult problems. The first could only be resolved by redesign of the shape of the packing rings, the second by attention to the surface condition of the tube and improving the oil outlet pipe. The total consumption of circulating oil is now about 0.00028 lb./h.p. hr.

Fouling and fires in the engine case

The oil leaks mentioned above gave rise to the carbonaceous deposits in the scavenge casing. After some hundreds of hours these caught fire and stopped the machine without any increase in the engine-case pressure.

This was overcome by reducing the engine-case temperature, which is maintained well below the critical carbonization temperature (230° C) by more intensive cooling of the compressor head plates and by improving the efficiency of the compressors, also by using oil better suited to the conditions of operation of the engine, elimination of the oil leaks mentioned above the certain hot spots.

Injection system

Together with the piston rings, this is the only feature of the diesel engine requiring maintenance which has been retained on free-piston engines. Much detail development work has had to be carried out on the injection pumps, the injectors, the injector holders, and on the precombustion chambers.

Central ring

This ring constitutes the combustion chamber where maximum pressures reach values of the order of (1,700 lb. per sq. in.). The maximum temperatures are also very high. The difficult problem of stresses due to thermal expansion at first involved failures, due to the fact that the part was made of steel and consequently particularly susceptible to corrosion fatigue. An appropriate design of the water circuit and the addition of anti-corrosives such as soluble oil or bichromate to the cooling water completely eliminated these incidents.

Valves

Some accidental failures occurred in the early days on the suction valves. These have disappeared completely since over two years ago. A new model of delivery valve with cast iron seats has given rise to incidents due to fitting errors.

PROBLEMS OF DAILY OPERATION

These chiefly affect the engine-room staff. They therefore greatly affect the opinion of the ship's engineers, a particularly important point when new machines are involved, which are often not welcome at first.

The mechanical noise of the engine is very acceptable. It is less than the noise from a 600 r.p.m. diesel engine by reason of the removal of the various mechanical drives, of valves, rockers, and camshafts. Noise appears to come mainly from the injection pump drive, the injectors, the suction valves, and finally the engine explosion. Tests are in progress to reduce this.

The intake pulsations are sound waves similar to those observed on large piston compressors or large Roots blowers of two-stroke engines. They were very noticeable on board the first minesweepers, where solution of the problem was rendered difficult by reason of the small volume of the engine-room and the small space available for the intake casings.

On the coasters, on the other hand, the problem was solved almost immediately and the intake has not given rise to any observation on the part of the ship's engineers.

A still more satisfactory solution has been developed recently for use on sets of the Liberty-ship type, comprising a greater number of cylinders. This new solution was fitted to the first type GS-34 gas generator in operation in England.

The exhaust makes absolutely no noise except when the maneuvering control wheel is at "Stop" on vessels not fitted with the recirculation valve. The expansion in the turbines is then insufficient to provide complete damping of the exhaust sound waves of the gas generator.

The temperature of the engine-room is very acceptable, since the engines draw in air directly from the engineroom, resulting, for example, in the case of the Liberty ship, in a renewal of air at the rate of 24 kg. per second. The temperature rise of the engine-room due to operation of the engines is in the order of 9° to 11° F. All the gas pipes under pressure are lagged but as their temperature is low, 788° F, there is no difficulty in obtaining good lagging. Finally, no part of the engine radiates directly into the engine-room, thus obviating the sensation of heat often observed in the neighborhood of the exhaust pipes of diesel engines.

The duties of the personnel are reduced to a minimum: —

There is only one manual lubricating point on the gas generator which is lubricated only once every twenty-four hours.

The independence of the gas generator and turbine obviates the necessity for frequent adjustment of auxilary circuits, rendered necessary on diesel

engines by the rapid variation in power developed as a function of the r.p.m. of the propeller shaft. This has agreeably surprised the ship's engineers.

During maneuvers the gas generators are not stopped.

Between the 2,500-hour strips the maintenance work is reduced strictly to inspection of the injectors.

The distances to be covered by the engine-room crew are small. The various control arrangements are centralized on a single panel.

The engine installation is situated entirely on one level and does not carry any platforms, except in some very special cases such as sets of very high power.

The dimensions of the main engine are very small.

The problems of annual operation are brought out clearly in Tables II, III and IV.

Up to the present, maintenance on the various vessels fitted with free-piston gas generators has always been carried out on board ship without it ever being necessary to take a gas generator out of the engine-room.

The personnel of the coasting vessels *Cantenac* and *Merignac* have appreciated the small dimensions and limited weight of the components to be handled, which are always within arm's reach.

Finally, the figures given at the beginning of the report show that immobilization of *Cantenac* and *Merignac* has been extremely short, despite two very unfavorable factors, namely:—

First gas generators in the production series.

Propulsion unit comprising only two gasifiers.

CONCLUSION

As with any heat engine, efforts must now be made towards improvement of performance: power per unit, fuel oil and lubricating oil consumption; but this concerns particularly the manufacturer and licencees of the GS-34; the number of the latter now gives rise to hopes for accelerated progress by the large number of engineers joining the team formed at the beginning by S.E.M.E. and S.I.G.M.A. But parallel with this, an effort of imagination appears necessary on the part of the builders and operators of ships in order to make the best use possible of an engine whose flexibility of adaptation is very superior to that of the engines which have preceded it. If the first free-piston installations have cautiously followed the paths traced by the diesel engine and the steam turbine, the years to come will certainly give birth to fresh solutions for the auxiliaries and for the architecture itself of free-piston vessels.

The free-piston engine is now fully established among other types of propulsion machinery sets. It remains to be seen with what speed and to what extent and for what applications the free-piston engine sets will replace the conventional engines.

TABLE II—*Intervals Between Inspections and Maintenances Man-Hours*

Interval	Parts inspected	Time for inspection	Number of man-hours
Hours		Hours	
2,500	Moving parts	4	12
5,000	Glands	8	32
10,000	Engine case	—	—
20,000	Exhaust cylinder liner	20	60
20,000	Scavenge cylinder liner	20	60
20,000	Overall inspection	40	120

TABLE III—*Wear Observed on a GS-34 Gas Generator*

Part	Wear, per 1,000 hours	
	mm.	in.
Exhaust cylinder liner	0.08	0.0032
Scavenge cylinder liner	0.055	0.0027
First diesel piston ring—exhaust end	0.27	0.0107
First diesel piston ring—scavenge end	0.16	0.0063
Wear on other diesel piston rings	0.08	0.0032
Wear on compressor cylinder	0.05	0.0020
Wear on compressor piston rings	0.08	0.0032

Power: 1,000 s.h.p. Fuel: Bunker C, viscosity varying between 2,200 and 3,200 sec., Redwood I at 100° F. Lubricating oil: Rimula 40 special and Talona 20.

TABLE IV—*Intervals Between Component Replacement*

Interval	Parts to be replaced	Number
2,500 hr.	Top engine piston rings	2
5,000 hr.	Injectors	1 set
10,000 hr.	Gland	—
	Bearing bands	—
	Injection wearing parts	—
	Ordinary engine piston rings	—
	Guide tube slippers	2
20,000 hr.	Fuel pump drive slippers and push rods	—
	Engine cylinder liner, exhaust end	1
	Oil outlet tubes	2
	Synchronizing rods	2
	Guide tubes	2
Interval indefinite but greater than 10,000 hr.	Engine cylinder liner, scavenge end	1
	Injector housings	—
	Central ring of engine cylinder	1
	Engine pistons	2
	Compressor piston rings	4
	Suction vaive blades	—
	Delivery valve plates	—

J. GRAVROGKAS

A NEW STANDPOINT IN REGARD TO THE QUESTION OF THE SUITABILITY OF GYROSCOPIC STABILIZATION OF NAVAL SHIPS

THE AUTHOR

was born in Lithuania on February 5, 1885. In 1915 he was graduated as Engineer Technologist from Technological Institute at Petersburg (Russia). In 1920 he returned to Lithuania and delivered lectures on Descriptive Geometry and Technical Mechanics at the University of Vytautas the Great in Kaunas, Lithuania. He was later offered a chair of Technical Mechanics. In 1941 he was appointed to be the President of the same University and held this position until 1944. In 1944 he left Lithuania and delivered lectures on Mechanics at the Baltic University in Germany until his emigration to the United States in the autumn of 1949. He sought a teaching position in the United States but before he could attain sufficient proficiency in the English language, he suffered physical disability which precluded his continuance in an active profession.

AT THE PRESENT TIME there exists a definite acceptance of the opinion that gyroscopic stabilization of the rolling of ships has been sufficiently investigated. In this connection, it is believed that it has been made quite clear that gyroscopes are not suitable for the purpose of stabilization of naval ships.

The purpose of this article is to prove that the above mentioned opinion is wrong, and that, as methodical investigation of the gyroscopic stabilization of ships has not yet been performed, we have no sufficient experimentally proven results to decide the said question.

As it is known the equations of the rolling of the gyroscopic stabilized ships are as following:

$$1.\ I_y\frac{d^2\phi}{dt^2} - I_z\,\omega\frac{d\psi}{dt} + M_s\,\phi - M_s\,\phi\sin\gamma\,t = 0$$

$$2.\ I_x\frac{d^2\psi}{dt^2} + I_z\,\omega\frac{d\phi}{dt} + m_s\,\psi + m_z\frac{d\psi}{dt} = 0$$

The first differential equation represents the equation of the rolling motion of a ship and the second the equation of the oscillatory motion of a gyroscope together with its frame within the ship.

In equation 1, I have deliberately omitted the damping term, which might be designated $N\frac{d\phi}{dt}$, because my purpose is to clear up the question of how the mechanical factors that arise from the gyroscopical arrangement, the changing of which is in our disposition, act upon the ship. The moment of the friction between the surface of the ship and water, which is designated by term $N\frac{d\phi}{dt}$, is not such a factor, that can essentially change mechanical meaning of the gyroscopical arrangement of the gyroscopically stabilized ship. Therefore the supposition, that the moment $N\frac{d\phi}{dt}$ is equal to zero and can be omitted in the equation, can not diminish the meaning of the conditions for a very slight rolling of the ship, that depends upon the proper gyroscopical arrangement as well as upon certain mechanical values of the ship.

We can be sure that the same conditions are valid in the case when the moment $N\frac{d\phi}{dt}$ is of its usual value.

In the same way the famous German scientist Prof. Dr. R. Grammel in his work "Der Kreisel, Seine Theorie und Seine Anwendung" searched for most favorable values of the swing number and of the brake number. Solving this problem he supposed that the damping number, which is herein designated as N, because of its small order of magnitude, is equal to zero. This supposition make the term $N\frac{d\phi}{dt}$ equal to zero. I think the moment $N\frac{d\phi}{dt}$ could be omitted not only for its small magnitude, but for the reason that it was not essential for solving the mentioned problem.

In equations 1 and 2:

I_y = the moment of inertia of the ship and the gyroscope within it about the longitudinal axis of the ship.

I_x = the moment of inertia of the gyroscope together with its frame about the transverse axis about which the frame rotates.

I_z = the moment of inertia of the gyroscope about its axis.

M_s = the result obtained by multiplying the weight of the ship by its metacentric height. This result is referred to as the moment of oscillation of the ship.

m_s = the product of the weight of the gyroscope and its frame by the distance from their center of gravity to the transverse axis about which the frame rotates. This is referred to as the moment of oscillation of the gyroscope and its frame.

m_z = the brake moment acting upon the frame of the gyroscope. Its magnitude corresponds to the unit of the angular velocity of the frame. This moment is referred to as the brake number.

ω = the axial angular velocity of the gyroscope.

γ = the frequency of oscillation of the ocean waves.

ϕ_o = the maximum angle of inclination of the waves.

ϕ = the heeling angle of the ship.

ψ = the angle of inclination between the axis of the gyroscope and the high axis of the ship.

Unknowns ϕ and ψ of the differential equations 1 and 2 can be expressed in terms of t by formulas:

$$\phi = A \sin \gamma t + B \cos \gamma t$$
$$\psi = A_1 \sin \gamma t + B_1 \cos \gamma t$$

A, B, A_1, and B_1 are constants.

Replacing in equations 1 and 2 these values of ϕ and ψ respectively we obtain equations:

$$(-I_y A\gamma^2 + I_z \omega B_1 \gamma + M_s A - M_s \phi_o) \sin \gamma t + (-I_y B \gamma^2 - I_z \omega A_1 \gamma + M_s B) \cos \gamma t = 0$$
$$(-I_x A_1 \gamma^2 - I_z \omega B \gamma + m_s A_1 - m_z B_1 \gamma \sin \gamma t + (-I_x B_1 \gamma^2) + I_z \omega A \gamma + m_s B_1 + m_z A_1 \gamma) \cos \gamma t = 0$$

Because these equations are identical, by equating the expressions in the parentheses to zero, we obtain four linear equations in four unknown constants A, B, A_1 and B_1:

$$A \cdot 0 - BI_z \omega \gamma + A_1 (m_s - I_x \gamma^2) - B_1 m_z \gamma = 0$$
$$AI_z \omega \gamma + B \cdot 0 + A_1 m_z \gamma \sin \gamma t + B_1 (m_s - I_x \gamma^2) = 0$$
$$A (M_s - I_y \gamma^2) + B \cdot 0 + A_1 0 + B_1 I_z \omega \gamma = M_s \phi_o$$
$$A \cdot 0 + B (M_s - I_y \gamma^2) - A_1 I_z \omega \gamma + B_1 \cdot 0 = 0$$

We solve these equations for the constants A and B:

$$A = \frac{\begin{vmatrix} 0 & -I_z \omega \gamma & (m_s - I_x \gamma^2) & -m_z \gamma \\ 0 & 0 & m_z \gamma & (m_s - I_x \gamma^2) \\ M_s \phi_o & 0 & 0 & I_z \omega \gamma \\ 0 & (M_s - I_y \gamma^2) & -I_z \omega \gamma & 0 \end{vmatrix}}{\begin{vmatrix} 0 & -I_z \omega \gamma & (m_s - I_x \gamma^2) & -m_z \gamma \\ I_z \omega \gamma & 0 & m_z \gamma & (m_s - I_x \gamma^2) \\ (M_s - I_y \gamma^2) & 0 & 0 & I_z \omega \gamma \\ 0 & (M_s - I_y \gamma^2) & -I_z \omega \gamma & 0 \end{vmatrix}}$$

Replacing the determinants by their expansions we have for A such expression:

$$A = \frac{M_s \phi_o \{ -I_z^2 \omega^2 \gamma^2 (m_s - I_x \gamma^2) + (M_s - I_y \gamma^2)[(m_s - I_x \gamma^2)^2 + m_z^2 \gamma^2] \}}{I_z^4 \omega^4 \gamma^4 - 2I_z^2 \omega^2 \gamma^2 (M_s - I_y \gamma^2)(m_s - I_x \gamma^2) + (M_s - I_y \gamma^2)^2 [(m_s - I_x \gamma^2)^2 + m_z^2 \gamma^2]}$$

$$B = \frac{\begin{vmatrix} 0 & 0 & (m_s - I_x \gamma^2) & -m_z \gamma \\ I_z \omega \gamma & 0 & m_z \gamma & (m_s - I_x \gamma^2) \\ (M_s - I_y \gamma^2) & M_s \phi_o & 0 & I_z \omega \gamma \\ 0 & 0 & -I_z \omega \gamma & 0 \end{vmatrix}}{\begin{vmatrix} 0 & -I_z \omega \gamma & (m_s - I_x \gamma^2) & -m_z \gamma \\ I_z \omega \gamma & 0 & m_z \gamma & (m_s - I_x \gamma^2) \\ (M_s - I_y \gamma^2) & 0 & 0 & I_z \omega \gamma \\ 0 & (M_s - I_y \gamma^2) & -I_z \omega \gamma & 0 \end{vmatrix}}$$

or

$$B = \frac{-M_s \phi_o I_z^2 \omega^2 \gamma^3 m_z}{I_z^4 \omega^4 \gamma^4 - 2I_z^2 \omega^2 \gamma^2 (M_s - I_y \gamma^2)(m_s - I_x \gamma^2) + (M_s - I_y \gamma^2)^2 [(m_s - I_x \gamma^2)^2 + m_z^2 \gamma^2]}$$

For heeling angle ϕ we have the expression:

$$\phi = A \sin \gamma t + B \cos \gamma t$$

We are interested in maximal magnitude of ϕ

$\phi_{max} = \sqrt{A^2 + B^2}$

$\phi^2_{max} = A^2 + B^2$

By substitution in the last equation respective expressions for A and B and simplifying the result we obtain:

$$\phi^2_{max} = M_s^2 \phi_o^2 \frac{(m_s - I_x\gamma^2)^2 + m_z^2\gamma^2}{[I_z^2\omega^2\gamma^2 - (M_s - I_y\gamma^2)(m_s - I_x\gamma^2)]^2 + (M_s - I_y\gamma^2)^2 m_z^2\gamma^2}$$

By multiplying the numerator and denominator of the fractional expression for ϕ^2_{max} by $\frac{I_y^2}{I_x^2} \times \frac{1}{M_s^2}$, it is given a more convenient shape:

$$\phi_{max} = \phi_o^2 \frac{\left(\frac{\frac{m_s}{I_x}}{\frac{M_s}{I_y}} - \frac{\gamma^2}{\frac{M_s}{I_y}}\right)^2 + \frac{\gamma^2}{\frac{M_s}{I_y}} \cdot \frac{\left(\frac{m_z}{I_x}\right)^2}{\frac{M_s}{I_y}}}{\left[\frac{I_z^2\omega^2}{I_x I_y} \cdot \frac{\gamma^2}{\frac{M_s}{I_y}} - \left(1 - \frac{\gamma^2}{\frac{M_s}{I_y}}\right)\left(\frac{\frac{m_s}{I_x}}{\frac{M_s}{I_y}} - \frac{\gamma^2}{\frac{M_s}{I_y}}\right)\right]^2 + \left(1 - \frac{\gamma^2}{\frac{M_s}{I_y}}\right)^2 \frac{\left(\frac{m_z}{I_x}\right)^2}{\frac{M_s}{I_y}} \frac{\gamma^2}{\frac{M_s}{I_y}}}$$

An analysis of the immediately foregoing formula shows that the maximum heeling angle of the ships depends upon the following ratios: $\frac{m_s}{I_x}$, $\frac{M_s}{I_y}$, $\frac{m_z}{I_x}$, $\frac{I_z^2\omega^2}{I_x I_y}$

and upon the frequency γ of the waves as well as upon the maximum angle ϕ_o of inclination of the waves and therefore upon the rolling moment $M_s \phi_o \sin \gamma t$ which acts upon the ship on the ocean.

In the stabilizing of ships by means of a gyroscope it is important to know how the proposed means of stabilizing will affect the ship as soon as it is tossed about the ocean waves. It has heretofore been necessary for the purpose of such determination to take the ship to sea. This method is inconvenient and disadvantageous because it does not allow a general decision to be made. To make a general and final decision about gyroscopical stability of ships, it is necessary to have a possibility of realizing on ships (that are destined for investigation of their gyroscopical stability) the various magnitudes of the above mentioned ratios and their various combinations. However this means of experimentation would involve the use of many ships and would thus prove very expensive. Thus economical reasons make its practical realization impossible.

However such investigation can be performed in a laboratory. For this purpose I have constructed a device, which enables the following things to be accomplished:

1. The representation by means of movable parts of the rolling motion of any ship which is stabilized by means of a gyroscope.
2. The provoking of the rolling moment which should correspond to any strength of the waves.
3. The selection, in a most effective way, of stabilizing equipment necessary to stabilize a ship subjected to tossing about by waves.

The parts of the device will become apparent during the course of the following description taken in connection with the accompanying drawings, in which like numerals designate like parts throughout, and in which:

Fig. 1 is a side elevational view of one side of the device;

Fig. 2 is a side elevational view of the opposite side of the device;

Fig. 3 is a view partly in elevation and partly in section, showing the construction of various parts of the device;

Fig. 4 is a transverse cross-section view taken on the line A-B of Fig. 3, and

Fig. 5 is an elevation detail of certain related parts of the device whereby motion of rotation is converted into reciprocating motion.

The essential part of the device is a pendulum 10 to which a shaft 11, journalled at its ends in standards 12 and 13 of a frame 14, is rigidly secured. The pendulum 10 embodies spaced channel-shaped members 21 and 22, the upper and lower ends of which are connected by similar channel-shaped transverse members welded to the members 21 and 22. The plates 23 and 24 which are secured to the aligned flanges 25 and 26 and to the aligned flanges 27 and 28 of the members 21 and 22, carry the shaft 11.

Threaded round bars 29 and 30 are located on one side of and parallel to the members 21 and 22, and similar bars 31 and 32 are located on the other side of and parallel to these members. The bars 29 and 31 are secured to the top thereof by means of Z-shaped clips 33 and 34 bolted, respectively, to the flanges 25

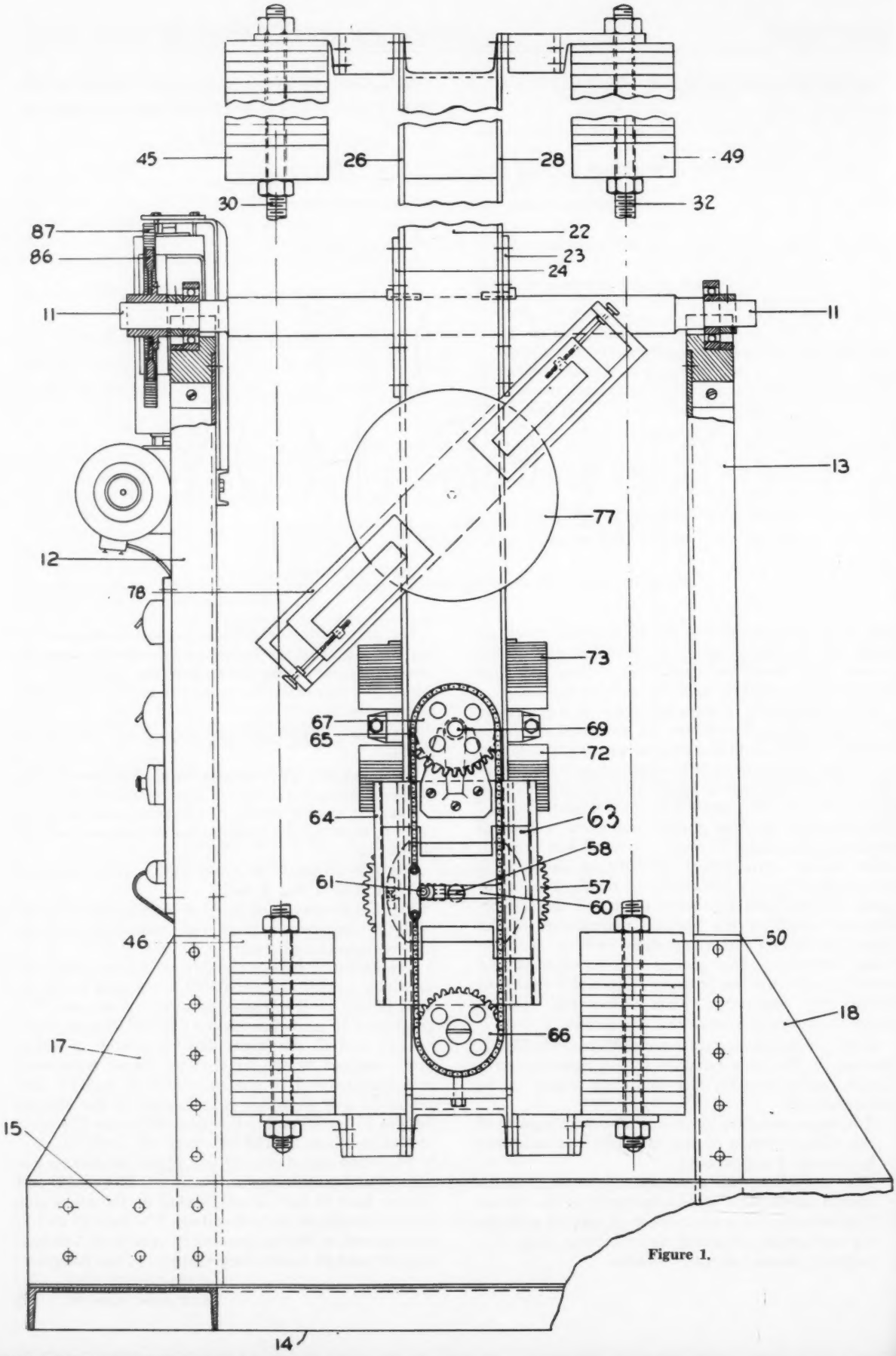
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Figure 1.

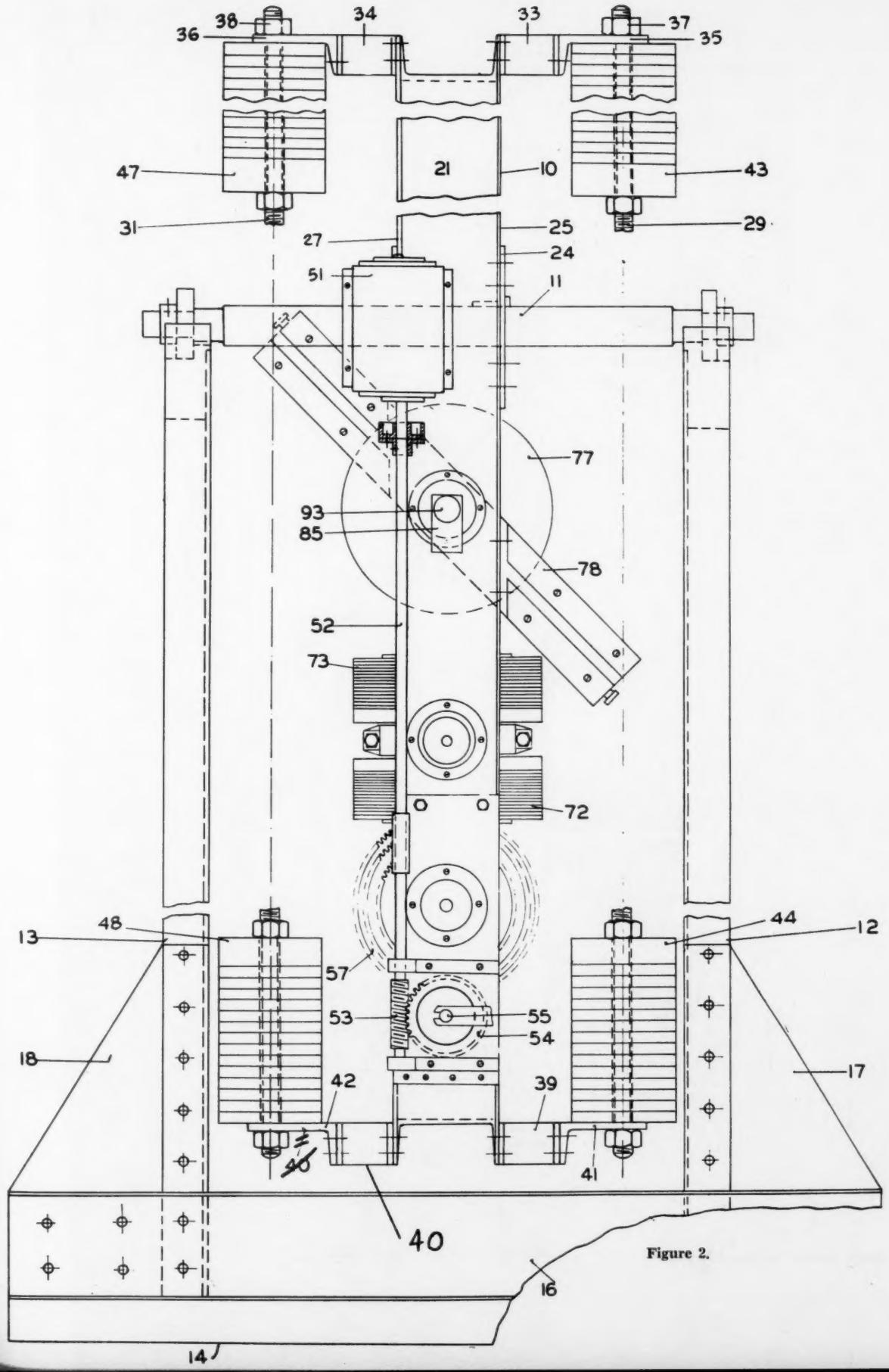
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Figure 2.

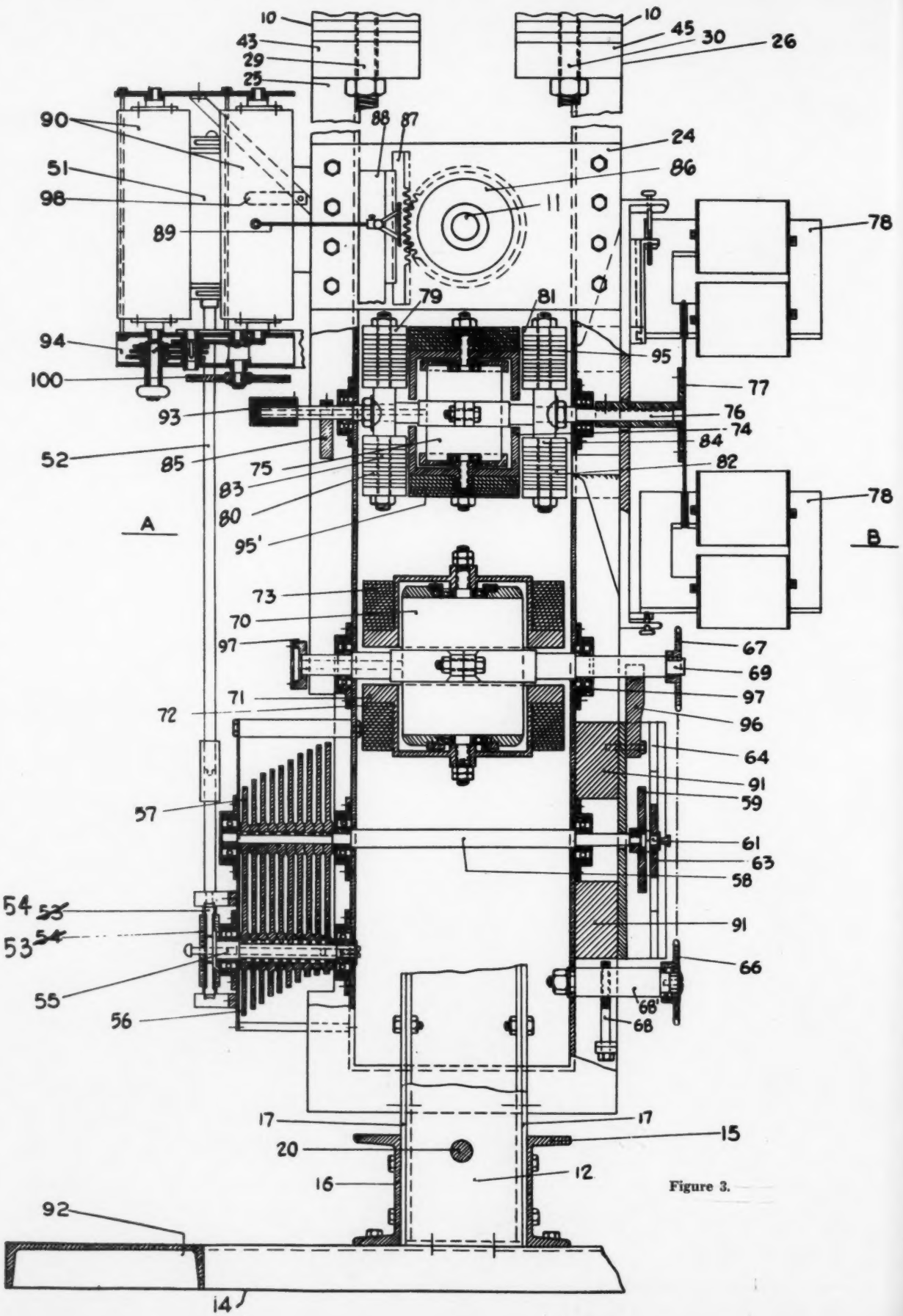
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Figure 3.

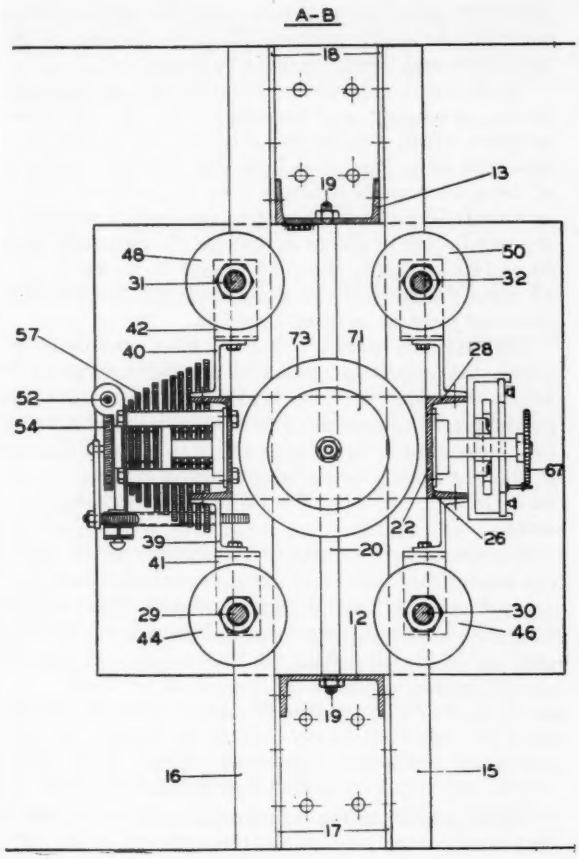

Figure 4.

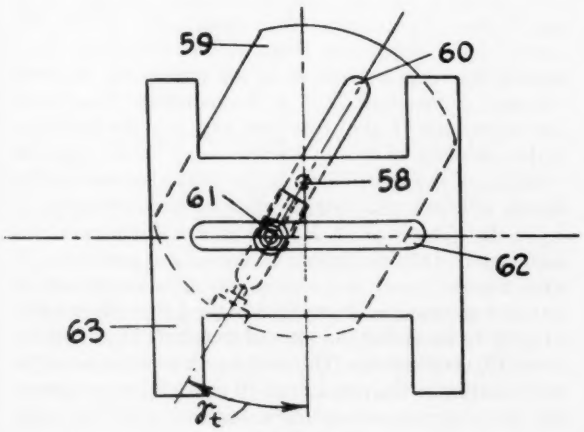

Figure 5.

and 27, and angle members 35 and 36 bolted to the clips. The upper ends of the bars 29 and 31 are threaded and extend through openings in the angle members to which they are secured by nuts 37 and 38 threaded upon the ends of the bars. The bars 29 and 31 are similarly secured at their lower ends in spaced relationship to the member 21 by means of Z-shaped clips 39 and 40 and angle members 41 and 42 into which the bars extend. The bars 30 and 32 are similarly secured to the channel-shaped member 22 of the pendulum.

The bars 29, 30, 31 and 32 carry internally threaded weights 43 and 44, 45 and 46, 47 and 48, and 49 and 50, respectively. This permits the weights to be adjusted along the bars and thereby vary the moment of inertia of the pendulum about axis of the shaft 11 so that its height may be kept within reasonable limits.

Before explaining how the swinging of pendulum 10 can represent the rolling of any gyroscopically stabilized ship that is affected by any wave, I will set forth certain clarifying observations. The expression $M_s \cdot \phi$ is equal to and is applicable to pendulum 10 of the device as well as of the ship. When the equation $M_s\phi = Q \cdot H \cdot \phi$ is applied to the pendulum, Q equals the weight of the pendulum and H equals the distance from center of gravity of the pendulum to the axis about which the pendulum swings. Correspondingly the expression M_s and ϕ equal the moment of oscillation and the angle of deflection of the pendulum. When the equation $M_s\phi = Q \cdot H \cdot \phi$ is applied to the ship, Q equals the weight of the ship, H the metacentric height, ϕ the heeling angle and M_s the moment of oscillation of the ship. Obviously, the moment $M_s\phi$ acts upon the pendulum in the same way as the analogous moment acts upon the ship.

There is another moment which also acts upon the ship from without. This is the rolling moment $M_s \cdot \phi_0 : \sin \gamma t$. M_s in this expression equals the oscillation moment of the ship. An analogous moment must be applied to the pendulum. If the expression $M_s \cdot \phi_0 \sin \gamma t$ is applied to the pendulum M_s equals the oscillation moment of the pendulum. The rolling moment $M_s \cdot \phi_0 \cdot \sin \gamma t$ which must act on the pendulum is realized by the following mechanism.

A motor 51 is secured upon the pendulum 10. The shaft 52 of the motor lies parallel to the pendulum and is extended and connected to a worm 53 which is in mesh with a worm gear 54 fixedly secured upon a shaft 55. A series of gears 56 of progressively decreasing diameter is mounted upon shaft 55. The gears of this series are adapted to mesh selectively with the corresponding gears of a series of gears 57 of progressively increasing diameter so as to vary the angular velocity of shaft 58 upon which the gears of the later series are mounted.

A disc 59 is fixedly secured upon one end of shaft 58. The disc is formed with a diametrical slot 60 through which a bolt 61 extends for fastening to the

disc at various distances from its center. The bolt 61 extends through a slot 62 formed in a slide 63 which is guided in its vertical linear movement by a frame 64. The disc and bolt accordingly impart a vertical reciprocating motion to the slide 63 the extent of which is determined by the distance of the bolt from the center of the disc.

A sprocket chain 65 is secured to the slide 63 and passes around sprocket wheels 66 and 67. The lower sprocket wheel is rotatably mounted upon a stub shaft 68 secured to member 22 of the pendulum 10. The upper sprocket wheel 67 is rigidly mounted upon a shaft 69 which is journalled in the members 21 and 22 of the pendulum. The shaft 69 embodies a ring in which the electric motor 70 of a gyroscope 71 is firmly held. Separate discs 72 and 73 are mounted upon the shaft of the motor and constitute selectively variable flywheels for the gyroscope.

It will be shown below that the angular velocity of the shaft 58 corresponds to the frequency of the ocean waves. The disc 59, which is fastened upon shaft 58 accordingly rotates with an angular velocity γ as does the bolt 61. When the bolt is placed at a distance r from the center of the disc and rotates with an angular velocity γ, it describes from its lowest position during time t an angle γt and therefore its vertical displacement equals $(r - r \cos \gamma t)$ (Fig. 5). Since this is also the vertical displacement of the slide 63 through which bolt 61 extends, the velocity of the slide is $r\gamma \sin \gamma t$.

The motion of the slide is transmitted to the sprocket wheels 66 and 67 by means of the chain 65 fastened to the slide. The peripheral velocity of the sprocket wheels is therefore $r\gamma \sin \gamma t$ and their angular velocity $\omega_1 = \frac{r \gamma \sin \gamma t}{R}$, where R equals the radius of the wheels.

The sprocket wheel 67 is fastened upon and transmits its rotation to the shaft 69 which carries the motor 70 of the gyroscope 71. When the sprocket wheel 67 rotates clockwise through a certain angle and then counter-clockwise through the same angle the gyroscope 71 swings with the angular velocity ω_1 about the axis of shaft 69. Therefore a moment $I\,\omega_2\,\omega_1$ arises. Since $\omega_1 = \frac{r \gamma \sin \gamma t}{R}$, $I\,\omega_2\,\omega_1 = \frac{I\,\omega_2\,r\,\gamma \sin \gamma t}{R}$ where I equals the moment of inertia of the gyroscope 71 about its axis and ω_2 its angular velocity about its axis. The moment $\frac{I\,\omega_2\,r\,\gamma \sin \gamma t}{R}$ acts upon the pendulum and realizes the rolling moment $M_s\,\phi_o \sin \gamma t$, which corresponds to the analogous rolling moment which acts upon the ship on the ocean, so that $\frac{I\,\omega_2\,r\,\gamma \sin \gamma t}{R} = M_s\,\phi_o \sin \gamma t$. In the foregoing equation the angular velocity γ of the shaft 58 corresponds to the frequency of the ocean waves, the relation $\frac{r}{R}$ corresponds to the greatest angle of inclination of the ocean waves and therefore must be equal to ϕ_o, and the product $I\,\omega_2\,\gamma$ corresponds to the moment M_s of oscillation of the pendulum and therefore must be equal to it.

To obtain the stabilizing moment, which must act on the pendulum and correspond to the analogous moment which acts on the ship, the gyroscope 74 is mounted upon the pendulum. The electric motor 75 of the gyroscope 74 is firmly held in a ring embodied in a shaft 76 journalled in the members 21 and 22 of the pendulum 10 above gyroscope 71. Separate discs 95 and 95′ similar to the discs 72 and 73 can be mounted upon the ends of the shaft of motor 75 and serve the same purpose as discs 72 and 73.

The shaft 76 carries a disc 77 which revolves between the adjustable poles of an electromagnet 78 which therefore exerts a braking moment upon the gyroscope 74 whose function is to stabilize the swing of the pendulum. In place of adjustable poles, change in the current of the electromagnet 78 may be resorted to in order to vary the value of the braking moment.

The moment of inertia of the gyroscope 74 about the axis of the shaft 76 is made variable by means of pairs of weights 79 and 80, and 81 and 82. The weights 79 and 80 are adjustably mounted upon a rod 83 suitably secured to the shaft 76. The weights 81 and 82 are adjustably mounted upon a rod 84 secured to the shaft 76. Various weights 85 can be secured to the shaft 76 which are heavy enough to change the frequency of oscillation of gyroscope 74 about the shaft 76 and can help to establish it at the proper value.

Turning again to the differential equations 1 and 2 (the first of which represents the equation of the rolling motion of a gyroscopically stabilized ship and the second the equation of the oscillatory motion of a gyroscope together with its frame within the ship) I wish to state that these equations are applicable to the swinging of pendulum 10 and to the oscillation of the pendulum gyroscope 74. If the equations 1 and 2 are applied to the swinging of pendulum 10 and to the oscillation of gyroscope 74, I_y means the inertia moment of the pendulum about the axis of shaft 11, I_x means the inertia moment of the gyroscope 74 about the axis of the shaft 76, I_z is the moment of inertia of the gyroscope 74 about its own axis, ω is the axial angular velocity of the gyroscope 74, γ is the angular velocity of the shaft 58, m_z is the brake number of the brake moment which is exerted by electromagnet 78 upon the gyroscope 74, M_s and m_s are the moments of oscillation of the pendulum 10 and of the gyroscope 74 about axes 11 and 76, respectively. The pendulum 10 and the gyroscope 74 are so designed that the centers of gravity lie under the axes of the shaft 11 and of the shaft 76, respectively. This is done to assure the vertical position of the pendulum 10 and of the gyroscope 74 when they are at rest. The angles ϕ and ψ in equations 1 and 2 mean the deflections of pendulum 10 and gyroscope 74 from their vertical position, respectively. If the equal weights 43-50 of the pendulum 10 that are constituted of a given number of plates are placed at the maximum distance from the shaft 11, the value

of I_y is maximum and can be denoted as $I_{y\,max}$. The value of I_x can be denoted as $I_{x\,max}$ if the weights 79-82 of the gyroscope 74 are constituted of the maximum number of plates.

To simplify the problem of representing the rolling of the ship by swinging of the pendulum 10 of the device, we regulate the weights 43-50 and 79-82 so that the least value of frequency $\sqrt{\frac{M_s}{I_{y\,max}}}$ of free oscillation of pendulum 10 and the least value of the frequency $\sqrt{\frac{m_s}{I_{x\,max}}}$ of free oscillation of gyroscope 74 are equal. These equal values we denote by S. If it is necessary to increase the value of the frequency $\sqrt{\frac{M_s}{I_{y\,max}}}$ we achieve it by moving the weights of the pendulum. We move them so that the displacement of upper weights 43, 45, 47 and 49 from their extreme position would be equal to the displacement of the lower weights 44, 46, 48 and 50 from their extreme position. The mentioned displacements must be equal if we wish to retain the value of M_s. To increase the value of the frequency $\sqrt{\frac{m_s}{I_{x\,max}}}$ we can use accordingly smaller number of plates and place them at proper distance from shaft 76.

Let us assume that the frequency of free oscillation $\sqrt{\frac{M'_s}{I'_y}}$ of ship under consideration and the frequency of free oscillation $\sqrt{\frac{m'_s}{I'_x}}$ of the gyroscope together with its frame within the ship are bigger than S. In this case we must increase the frequency $\sqrt{\frac{M_s}{I_{y\,max}}}$ to make it equal to $\sqrt{\frac{M'_s}{I'_y}}$ and increase the frequency $\sqrt{\frac{m_s}{I_{x\,max}}}$ to make it equal to frequency $\sqrt{\frac{m'_s}{I'_x}}$. By equations $\sqrt{\frac{M'_s}{I'_y}} = \sqrt{\frac{M_s}{I_y}}$ and $\sqrt{\frac{m'_s}{I'_x}} = \sqrt{\frac{m_s}{I_x}}$ we determine the proper values of I_y and of I_x. The proper value of I_y we realize on the pendulum 10 by appropriately bringing the weights of the pendulum nearer to the shaft 11. Likewise the proper value of I_x must be realized by using accordingly a smaller number of plates and placing them at proper distance from shaft 76.* To determine the necessary value of the brake number that must be realized on the pendulum we use equation $\frac{m_z}{I_x} = \frac{m'_z}{I'_x}$, where I_x is already determined and m'_x means the brake number that is realized on the ship under consideration. By this equation we determine the necessary value of m_z. We can realize it on the pendulum by change in the current of electromagnet 78 which exerts a braking moment upon gyroscope 74 and can vary the value of the braking number. The swing number $\frac{(I_z\,\omega)^2}{I_y\,I_x}$ on the pendulum must be made equal to the swing number $\frac{(I_z\,\omega)'^2}{I'_y\,I'_x}$ that is realized on the ship under consideration. Thus we get equation $\frac{(I_z\,\omega)'^2}{I'_y\,I'_x} = \frac{(I_z\,\omega)^2}{I_y\,I_x}$. Because the proper values of I_y and I_x are already determined, we can from this equation determine the proper value of $(I_z\,\omega)$ that must be realized on the pendulum. We can realize it by change in the angular velocity ω of motor 75. Finally the products $I\,\omega_2\,\gamma$ must be made equal to M_s and ratio $\frac{r}{R}$ equal to ϕ_0. The proper value of product $I\,\omega_2\,\gamma$ can be achieved by change in angular velocity of the motor 70 of gyroscope 71, and the proper value of the ratio $\frac{r}{R}$ can be achieved by change in distance of bolt 61 from center of the disc 60. Because the ratios $\frac{M_s}{I_y}$, $\frac{m_s}{I_x}$, $\frac{m_z}{I_x}$ and $\frac{(I_z\,\omega)^2}{I_y\,I_x}$ that are realized on the pendulum are equal to the corresponding ratios which are realized on the ship under consideration, and because the rolling moment which acts upon the pendulum corresponds to the rolling moment which acts upon the ship, the swinging of the pendulum now represents the rolling of ship.

The device can be used to reproduce the rolling motion of ship if the frequency of its free oscillation $\sqrt{\frac{M''_s}{I''_y}}$ and if the frequency of free oscillation $\sqrt{\frac{m''_s}{I''_x}}$ of gyroscope together with its frame within the ship are equal but less than S. In this case we imagine that the rolling phenomenon of the ship under consideration is reduced. It may be assumed accordingly, that the ocean wave oscillation is accelerated n times and that the waves are correspondingly reduced without changing their shape. While the frequency of oscillation of the actual ocean waves is γ' yielding a period of oscillation of $\frac{2\pi}{\gamma'}$ the assumed fre-

* If we wish to simplify the operation with weights 79 to 81, inclusive, and make it as simple as is the operation with weights 43 to 50, inclusive, we must lengthen the rods 83 and 84 and mount on them the first mentioned weights in the same manner as the last mentioned weights are mounted on the bars 29, 30, 31 and 32. However, with lengthening of the rods 83 and 84 the distance between shafts 76 and 11 becomes increased. This results in increase of the size and the cost of the device.

quency and period of oscillation become γ_1 and $\frac{2\pi}{\gamma_1}$, respectively, where $\gamma_1 = n\,\gamma'$. On the other hand, it is assumed that the corresponding mechanical magnitudes, upon which the rolling motion of the ship under consideration depends, are so changed that the maximum heeling angle is retained. It can be obtained if the values of the ratios

$$\frac{\gamma_1^2}{\frac{M_s}{I_y}}, \frac{\frac{m_s}{I_x}}{\frac{M_s}{I_y}}, \frac{\frac{m_z}{I_x}}{\frac{M_s}{I_y}} \text{ and } \frac{(I_z\,\omega)^2}{I_y\,I_x} \cdot \frac{1}{\frac{M_s}{I_y}}$$

can be retained. A rolling phenomenon is then considered so that the moments of oscillation M_s and m_s retain their values and only the moments of inertia I_x, I_y as well as the product $(I_z\,\omega)$ and the brake number m_z change in value. These moments of inertia, the mentioned product and the brake number then become I_{1x}, I_{1y}, $(I_z\,\omega)_1$ and m_{1z}, respectively, so that the following equations are satisfied:

1. $$\frac{\gamma'^2}{\frac{M_s}{I_y}} = \frac{\gamma_1^2}{\frac{M_s}{I_{1y}}}$$

2. $$\frac{\left(\frac{m_z}{I_x}\right)^2}{\frac{M_s}{I_y}} = \frac{\left(\frac{m_{1z}}{I_{1x}}\right)^2}{\frac{M_s}{I_{1y}}}$$

3. $$\frac{\frac{m_s}{I_y}}{\frac{M_s}{I_y}} = \frac{\frac{m_s}{I_{1x}}}{\frac{M_s}{I_{1y}}}$$

4. $$\frac{(I_z\,\omega)^2}{I_x\,I_y} \cdot \frac{1}{\frac{M_s}{I_y}} = \frac{(I_z\,\omega)_1^2}{I_{1x}\,I_{1y}} \cdot \frac{1}{\frac{M_s}{I_{1y}}}$$

Since $\gamma_1 = n\,\gamma'$, the above equations are valid of $I_{1y} = \frac{I_y}{n^2}$, $I_{1x} = \frac{I_x}{n^2}$, $m_{1z} = \frac{m_z}{n}$ and $(I_z\,\omega)_1 = \frac{(I_z\,\omega)}{n}$. From the foregoing it is concluded that, if the period of oscillation of the ocean waves is reduced n times and if at the same time the moments of inertia I_x and I_y of the ship under consideration are reduced n^2 times and the product of the moment of inertia of the gyroscope stabilizer by its angular velocity $(I_z\,\omega)$ is reduced as well as the brake number n times, the maxmum heeling angle of the ship under consideration would be unchanged.

This conclusion has equal validity for every ship. It is also valid for the pendulum of the described device because the equations 1, 2, 3 and 4 expressed above are applicable as well to the pendulum. Of course we can only imagine the above mentioned change of oscillation of the sea waves as well as the corresponding changes in I_x, I_y, $(I_z\,\omega)$ and m_z of the ship. But all considered changes can be realized on the pendulum and in this way can be obtained the maximum heeling angle of the ship by means of the reduced rolling phenomenon.

When we have become acquainted with the use of the method of reduced rolling phenomenon, we can use our device to obtain the maximum heeling angle of a given ship of which the frequency of free oscillation $\sqrt{\frac{M''_s}{I''_y}}$ and the frequency of free oscillation $\sqrt{\frac{m''_s}{I''_x}}$ of gyroscope together with its frame within the ship are K times less than S, where $S = \sqrt{\frac{m_s}{I_{x\,max}}} = \sqrt{\frac{M_s}{I_{y\,max}}}$.

As to the effect upon the size of the pendulum it is not desirable to increase the length of the bars 29, 30, 31 and 32 on which weights 43 to 50, inclusive, are mounted. Likewise it is not desirable to increase the length of the rods 83 and 84 on which weights 79 to 82, inclusive, are mounted or to increase the size of the weights 43 to 50 and 79 to 82. We can consider, however, that the mentioned bars and rods are lengthened upwards and downwards and the weights moved away from the corresponding axes to the extent necessary to increase the moment of inertia $I_{y\,max}$ and $I_{x\,max}$ by a factor of K^2. We imagine that the lengthening upwards is equal to the corresponding lengthening downwards and therefore the moments of oscillation M_s and m_s retain their values. In terms of frequency of oscillation this signifies a reduction in the frequency of oscillation of the pendulum $\sqrt{\frac{M_s}{I_{y\,max}}}$ and in the frequency of oscillation of the gyroscope 74, $\sqrt{\frac{m_s}{I_{x\,max}}}$ by a factor of K times so as to make them equal to the values $\sqrt{\frac{M''_s}{I''_y}}$ and $\sqrt{\frac{m''_s}{I''_x}}$ of the ship under consideration. Stated algebraically, these equations become

$$\frac{1}{K}\sqrt{\frac{M_s}{I_{y\,max}}} = \sqrt{\frac{M''_s}{I''_y}} \text{ and } \frac{1}{K}\sqrt{\frac{m_s}{I_{x\,max}}} = \sqrt{\frac{m''_s}{I''_x}}.$$

Also the swing number and the ratio $\frac{m_z}{I_x}$ define the swing of the pendulum as well as the moment that acts upon the pendulum which corresponds to the analogous rolling moment which acts upon the ship under consideration. Since $I_{y\,max}$ and $I_{x\,max}$ are considered as being increased K^2 times the swing number $\frac{(I_z\,\omega)^2}{I_{y\,max}\,I_{x\,max}}$ becomes $\frac{(I_z\,\omega)^2}{I_{y\,max}K^2 I_{x\,max}K^2}$ that is, the swing number of the imagined pendulum is reduced K^4 times. Since the swing number of the considered

ship, represented as N, must equal swing number of the imagined pendulum, the equation $N=\frac{(I_z\,\omega)^2}{K^4\,I_{y\,max}\,I_{x\,max}}$ is obtained. This can be accomplished by changing the axial velocity of the gyroscope 74 so that product $(I_z\,\omega)$ becomes equal to product $(I_z\,\omega)''$. Then

$$\frac{(I_z\,\omega)''^2}{K^4\,I_{y\,max}\,I_{x\,max}}=N \text{ and } (I_z\,\omega)''=K^2\sqrt{N\,I_{y\,max}\,I_{x\,max}}\ .$$

Also the ratio $\frac{m_z}{I_{x\,max}}$ is reduced K^2 times since the moment of inertia $I_{x\,max}$ of the gyroscope about the transverse axis is increased K^2 times. Since the ratio $\frac{m_z}{K^2\,I_{x\,max}}$ of the imagined pendulum is to equal the corresponding ratio of the ship under consideration m_z becomes m''_z, which can be realized by change in the current of the electromagnet 78. If Q represents the mentioned ratio of the ship under consideration, then $Q=\frac{m''_z}{K^2\,I_{x\,max}}$ or $m''_z=Q\,K^2\,I_{x\,max}$.

Thus to cause the pendulum to represent the greatest angle of heel of the ship under consideration we must make m_z, $(I_z\,\omega)$, I_x and I_y as big as it is shown above. But to obtain the proper magnitudes of I_x and I_y the movement of the weights 43 to 50, inclusive, and 79 to 82, inclusive, as noted above, would be necessary. As explained such movement is undesirable and since without this movement the necessary values for $\frac{M_s}{I_y}$ and $\frac{m_s}{I_x}$ cannot be obtained the method of reduced rolling phenomenon is employed to reproduce a maximum angle of deflection of the pendulum equal to the maximum heeling angle of the ship under consideration. As mentioned above the frequency of oscillation of the ship is K times smaller than the maximum frequency of oscillation $\sqrt{\frac{M_s}{I_{y\,max}}}$ of the pendulum.

Employing the method of reduced rolling phenomenon the frequency of wave oscillation γ' is considered increased K times and the shape of the waves unchanged so that the greatest angle of inclination, ϕ_o of the waves remains the same.

Using the K times reduced rolling phenomenon, the moment of inertia of the imagined pendulum about its axis of swing which equals $I_{y\,max}\,K^2$ is reduced K^2 times so that it becomes equal to $I_{y\,max}$. This can be realized by placing the weights 43 to 50, inclusive, at the extreme positions shown. Similarly the moment of inertia of the gyroscope 74 about its transverse axis, the value of which was assumed to be $I_{x\,max}\,K^2$, must be reduced K^2 times and becomes $I_{x\,max}$. This is obtained by positioning the weights 79 to 82, inclusive, as shown. The magnitudes of the brake number m''_z and of the product $(I_z\,\omega)''$ must also be reduced and by an amount equal to K times. Then the value of the mentioned brake number becomes $Q\,K\,I_{x\,max}$ and the value of the mentioned product becomes $K\sqrt{N\,I_{y\,max}\,I_{x\,max}}$. The proper value of the brake number is obtained by changing the current in the electromagnet 78. The proper value of the mentioned product is obtained by changing the angular velocity ω of motor 75.

It was shown that moment $\frac{I\,\omega_2\,r\,\gamma'\sin\gamma' t}{R}$ acts upon the pendulum and realizes the rolling moment $M_s\,\phi_o\sin\gamma' t$ which corresponds to the analogous rolling moment which acts upon the ship on the ocean, and that $M_s=I\,\omega_2\,\gamma'$ where γ' is the frequency of the actual ocean waves. Because using the K times reduced rolling phenomenon we assume that the actual frequency γ' of the ocean waves is increased K times and becomes $K\gamma'$, we conclude that M_s must remain equal to the product $I\,\omega_2\,K\,\gamma'$, although the actual frequency of the waves is K times increased. Since the moment of oscillation of pendulum remains constant the product $I\,\omega_2\,K\,\gamma'$ must remain constant too. This is possible if product $I\,\omega_2$ is reduced K times. This can be realized by changing the angular velocity of the motor 70.

The using of the device to reproduce the maximum heeling angle of the ship by application of the reduced rolling phenomenon can be summarized in the following manner:

1. The weights 43 to 50, inclusive, are placed as far from the axis of swing of the pendulum as possible.
2. The weights 79 to 82, inclusive, are placed as shown.
3. The angular velocity of the motor 75 of the gyroscope 74 must be of such value that the product of the moment of inertia of mentioned gyroscope about its own axis by its angular velocity equals $K\sqrt{N\,I_{y\,max}\,I_{x\,max}}$ where N equals the swing number of the ship under consideration.
4. By the change of the current of the electromagnet 78, make the brake number equal to $Q\,K\,I_{x\,max}$, where Q equals $\frac{m''_z}{I''_x}$ of the considered ship.
5. By means of the series of gears 56 and 57, cause the shaft 58 to rotate with an angular velocity $K\gamma'$ where γ' is the frequency of oscillation of the ocean waves.
6. Fasten the bolt 61 to the disc 59 at such a distance r from the center of the disc that the ratio $\frac{r}{R}$ equals the greatest angle of inclination of the waves.
7. The angular velocity of the motor 70 of the gyroscope 71 must be made of such value that the product of the moment of inertia of the gyroscope about its own axis by its angular velocity equals $\frac{M_s}{K\gamma'}$, where γ' is the frequency of oscillation of the ocean waves.

The pendulum of the device is suitable to give a graphical picture of the rolling movement of a gyroscope stabilized ship. For this purpose a gear 86 is fixed upon shaft 11 so as to oscillate with the shaft. Gear 86 is meshed with a rack bar 87 sliding within a guide 88 carried by the standard 12, so that oscillation of the gear 86 produces a vertical reciprocating motion of the rack bar. A similar motion is produced in a stylus 89 secured to the rack bar. The stylus bears upon a paper wrapped around a drum assembly 90 which rotates at a constant speed so as to trace a curve upon the paper. An indicator diagram is thus formed, the ordinates of which are a measure of the angular deflections of the oscillation of the pendulum.

Ending this article I would like to remark that the pendulum of the device is fit not only to represent the maximum heeling angle of the rolling of the ship under consideration, but permits complete investigation of what values of the ratios $\frac{M_s}{I_y}$, $\frac{m_s}{I_x}$, $\frac{m_z}{I_x}$ and $\frac{I_z^2 \omega^2}{I_y I_x}$ and what combinations of them are most favorable. Moreover it is capable of demonstrating the gyroscopic action and can be used as a teaching device for leashed oscillations. It lends itself to more quantitative measurement than other models which demonstrate the action of the gyroscope.

The French physicist J. B. L. Foucalt invented the gyroscope in 1852, using it to demonstrate the earth's rotation. For nearly fifty years, it remained little more than a scientific toy, until Elmer A. Sperry developed the marine gyro-compass in 1911. Quickly adapted to aircraft instrumentation, naval gunnery control instruments, auto-pilots, and aircraft bombsights, the gyroscope won an important role in military applications in the next few decades. A striking and powerful application in World War II, developed by Dr. C. S. Draper, was its use in aircraft and anti-aircraft gun sights, where it automatically predicted and indicated the proper firing lead angle. Today it plays a vital role in the instrumentation of guided missiles by its use in stabilization and automatic navigation. Its promise in inertial navigation systems assures it of a continuing future in underwater, surface, air, and even space navigation.

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ENGINEERING ABSTRACTS

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50–57 "Application Problems with Petroleum Lubricants in Nuclear Power Plants"—R. F. Hausman and E. R. Booser; Lubrication Engineering, v. 13, n. 4, Apr. 1957, pp. 199–202. The nuclear power plant presents some entirely new problems with respect to lubrication of components. However, many of the lubrication requirements are not greatly different from present power plants. The following are particularly important: inspection of lubricants and equipment will be reduced; life of lubricants that are near the reactor may be reduced; life of gaskets, hose and paints may be reduced. Radiation effects on lubricant life in some components of a typical nuclear power plant are:

Component	Operating Dosage Level Rads/Hr	Lubricant Life-Hours to Attain 10^8 Rads Exposure
Turbine	0.2	10^9
Water Circulating Pump	10^2	10^6
Control Drive Mechanism	10^5	10^3

Adequate shielding, proper selection of lubricants and replacement of lubricants will minimize the problem.

51–57 "Review of Technical Progress by Brown Boveri in 1955/56"—The Brown Boveri Review, v. 44, n. ½, Jan./Feb. 1957, pp. 5–108. This review covers work that has been accomplished in a number of fields including: steam turbines, condensation and feed heating plants, atomic power plants, gas turbines, voltage regulation, switch gear relays, transformers, A.C. and D.C. motors, induction furnaces, medium frequency machines for induction heating, electric welding, compressors, gears, pressure charging, Diesel-electric traction. Photographs, curves, tables and drawings are included.

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52–57 "Working with Outside Engineering Firms"—A. W. Richards; Machine Design, v. 29, n. 8, Apr. 1957, pp. 114–118. Manpower, facilities and time can be obtained from outside engineering firms to aid in the solution of many varied problems. Types of engineering service organizations available include: management, design, process, industrial design, research, testing and market research. Advantages of obtaining services of outside organizations include the following: phases of a program can be handled by specialists; equipment and facilities can be rented; peak load demand for manpower can be met; isolation from day-to-day production problems is feasible; variety of new problems are handled by personnel with experience; problems can be approached with objectivity.

53–57 "The Packaging of Electronic Equipment"—S. C. Schuler; Journal of The Royal Aeronautical Society, v. 61, n. 557, May 1957, pp. 335–344. Moisture protection and mechanical shock protection are major problems in the protection of electronic equipment. Transit and handling shock and vibrations are discussed for vehicles, ships and aircraft. Vibrations on ships are generally in the range of 5–20 cps with amplitudes less than ± 0.03 in. Impact testing, cushioning materials, instrumentation in packaging investigations and packaging techniques are presented.

54–57 "Structural Steels for Warship Building, with some Notes on Brittle Fracture"—Victor Shepheard; North East Coast Institution of Engineers & Shipbuilders, v. 73, Part 6, Mar.-Apr. 1957, pp. 301–330. Developments in structural steels and hull structural design are discussed. Welding research, brittle fracture research, development of new structural steels and development of high yield point steels are reviewed. Tables, photographs, and charts.

55–57 "H. T. P. Cycle for Submarine Propulsion"—The Marine Engineer and Naval Architect, v. 80, n. 968, May 1957, pp. 159–161, The high test peroxide booster plant installed in H. M. Submarine *Explorer* is described. The submerged speed of the *Explorer* is believed to be considerably greater than that of the *Nautilus*. The vessel is propelled by twin screw double reduction geared turbines. The turbines are driven by a steam and carbon dioxide mixture which results from combustion of diesel oil in an atmosphere of oxygen and steam. Oxygen is formed by the decomposition of hydrogen peroxide. The turbine is of special design. Operation, transmission and fuel handling are described.

56–57 "Instrumentation of Steam and Gas Circuits"—Nuclear Engineering, v. 2, n. 14, May 1957, pp. 186–189. Steam and gas circuits in power reactors present instrumentation problems. The instruments and controls are grouped as those required for safe operation; to assist in efficient operation; to check on specific component performance over certain time periods. Safety valves, static pressure, flow measurement, gas analysis, heat exchangers, feed water regulators, oxygen analyzer and infra-red gas analyzers are discussed.

57–57 "New Compasses"—A. Hine; Research, v. 10, n. 3, March 1957, pp. 97–107. The work that resulted in development of the Admiralty gyro-magnetic compass is described. This compass contains the best features of both the gyroscopic and magnetic units. The gyro-magnetic compass is ready for use in approximately ten minutes after switching on, while the gyroscope compass may require an hour to settle and about five hours to run up.

58–57 "Bridging the Gap in the Gas Turbine's History"—C. W. Smith; General Electric Review, v. 60, n. 3, May 1957, pp. 8–12. A historical review of significant events in the development of the gas turbine is presented. The military need for this prime mover added materially to its rapid success in aviation fields. However, a number of ground power plants, including Holzwarth's designs, contributed to the success of aircraft engines. Development of the gas turbine is now pushing out into many fields.

59–57 "Columbium and Its Uses"—G. L. Miller; Materials & Methods, v. 45, n. 5, May 1957, pp. 131–135. Recent new discoveries of columbium minerals have been made in Nigeria, Uganda, Kenya and Canada. These new sources make columbium a metal that is no longer scarce. Columbium has better oxidation resistance than molybdenum. It also retains its ductility after being heated to elevated temperatures. Properties are dependent on the gas absorbed during processing. Hot working at 1800° F has been done by Battelle and the material still retained its ductility, indicating the oxide did not dissolve to any appreciable degree. Physical properties, corrosion resistance and mechanical properties are shown. Methods of production and fabrication are discussed. It has potential use in nuclear reactors because of its low neutron absorption cross section. Jet engine applications are also attractive because of its good properties at high temperature. References.

60–57 "Reheating as a Contribution to the Economy of the Marine Steam Turbine, with Special Reference to the Installation in the SS *Empress of Britain*"—A. W. Davis; The Shipbuilder and Marine Engine Builder, v. 64, n. 589, Mid April, 1957, pp. 295–301. The propulsion plant finally selected is described. Alternate designs that were considered are included. The plant incorporates two shafts at 13,500 S.H.P. each. Boiler maximum capacity is 123,000 lb. per hr. They are Foster Wheeler controlled superheater type, with two furnaces. Reheat boiler generates 58,000 lb. per hr. and will reheat 167,000 lb. per

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hr. from 610° F to 850° F. The high pressure and intermediate turbines are multi-stage impulse type. The low pressure turbine is double flow reaction type. The actual all-purpose fuel rate was 0.537 lb. per S.H.P.-hr. The propulsion fuel rate was 0.495 lb. per S.H.P.-hr. With the successful demonstration of the efficient operation of this reheat plant it is expected that the direct cycle will be less competitive in the future.

61–57 "Applications for Glass Materials and Components"—J. K. Davis; Electrical Manufacturing, v. 59, n. 6, June 1957, pp. 151–156, 384. Glass is widely used in a number of fields: for structural parts, glass components, and special purpose materials. As a structural material its unusual properties make it suited for electric lamp and electron tube enclosures. Sintered glass is used for television gun mounts, tube bases and headers. Metallized glass is suitable for hermetic and moisture impervious seals. Glass components include capacitors, resistors and ultrasonic delay lines. Special applications are: fused silica which can withstand gamma radiation up to 10^{10} roentgens and not show appreciable discoloration; photosensitive glass for electronic circuit boards; radiation-resistant glass which can serve as radiation shields and permit visual observation; conductive glass for power resistors and heating elements. References.

62–57 "High-Temperature Stainless Steel"—Edward A. Loria; Product Engineering, v. XXVII, n. 4, April 1957, pp. 135–139. Data is presented on eight stainless steels which were developed for airframes and also jet engines. These steels are suited for other applications where operating temperatures are in the 600–1400° F range. High temperature alloys, 1200–1400° F, include austenitic H N M, H T X and A-286. The moderate temperature alloys up to 1200° F, include: 17–7 P H, Am-350, 420, 422 and 422 M. Tensile, yield, rupture, heat treatment and fabrication data are presented.

63–57 "Research in 1956"—The Metropolitan-Vickers Gazette, v. XXVII, n. 452, March 1957, pp. 63–76. A review of some research work conducted by the company in 1956 includes: particle accelerators, high power radio valves, nuclear magnetic resonance, mass spectrometry, vacuum deposition of metals, semi-conductors, molecular distillation, metals, magnetic materials and equipment, acoustics, insulation and computation. In the field of acoustics work was done on gears, gas turbines, Diesels and marine power plants. Investigations were conducted to measure residual machining stress in gear teeth. Research was carried out on vibratory stresses in turbine and compressor blading. Extensive investigation was made of the creep properties of 3% chromium-molybdenum steel for steam turbine rotor forgings.

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64–57 "Review of Heat-Transfer Literature—1956"—E. R. G. Eckert, J. P. Hartnett, T. F. Irvine, Jr., and P. J. Schneider; Mechanical Engineering, v. 79, n. 5, May 1957, pp. 433–444. Papers on heat transfer published during October 1955-October 1956 are reviewed. Demands of aviation have resulted in new developments that have been responsible for research in heat transfer. Research effort has been done on: channel flow; natural convection heat transfer to rotating surfaces; transition from laminar to turbulent flow; behavior of heat exchangers under transient conditions; time response of instruments including thermocouples; heat transfer in boiling and in liquid metal. Bibliography includes the number of references as indicated in the following fields: heat conduction, 39; channel flow, 20; boundary-layer flow, 42; flow with separated regions, 4; natural convection, 14; free and forced convection from rotating surfaces, 8; transpiration and mass-transfer cooling, 12; change of phase, 12; radiation, 14; measurement techniques, 14; heat exchangers, 8; nuclear reactors, 5; aircraft and missiles, 10; thermal stress and shock, 11.

65–57 "Super Saturation in Steam Expanding from a Low Initial Quality"—D. J. Ryley; The Engineer, v. 203, n. 5285, May 10, 1957, pp. 708–713. Experimental and theoretical work on supersaturated steam is described. Experiments, results, a new three-phase flow theory, droplet growth factor, physics of droplet growth and promotion by reversion are included. It is concluded that, in low pressure turbines, considerable supersaturation will take pace in expansion elements where the state point locus crosses the nominal saturation limit. References.

66–57 "Centrifugal Boiler Compression Still"—K. C. D. Hickman; Industrial and Engineering Chemistry, v. 49, n. 5, May 1957, pp. 786–800. The salt-water conversion method, employing the Badger-Hickman still is described. This still incorporates a device that spreads the sea water out in a thin film and thus increases the rate of heat transfer to the water. It appears that the relative surface area of evaporator condenser can be reduced by a factor of 5 to 10 times. Material includes: early experiments, properties and parameters of stills, performance and experimental data.

67–57 "New Turbojet Test Beds"—The "Bristol" Quarterly, v. 2, n. 4, Spring 1957, pp. 87–91. Test beds suitable for engines of 25,000 lb. thrust, and with modifications up to 40,000 lb. thrust are provided. Engines with exhaust reheat up to 2000° K can be accommodated. Exhaust silencing is accomplished by twin detuners. Air intake silencing design includes a splitter system consisting of a series of sound-absorbent walls affording cranked passages. Primary and sec-

Number *Abstract Title*

ondary control rooms are described along with instrumentation. Engine speed is measured by a Decatron counter. Compressor washing is done with a distilled water and paraffin mixture.

68–57 "Residual Machining Stresses"—E. K. Henrikson; The Tool Engineer, v. XXXVIII, n. 4, Apr. 1957, pp. 92–96. Residual stresses caused by machining operations can result in serious failures of mechanical components. Origin, mechanism of stress formation, stress from single point tools, stress from milling cutters and grinding stresses are discussed. Proper machining operations can reduce these stresses.

69–57 "20,000—S. H. P. Nuclear Propulsion Plant"—R. P. Giblon and G. H. Kurtz; The Motor Ship, v. XXXVII, n. 442, Mar. 1957, pp. 518–522. The design features of a 20,000 SHP closed cycle gas turbine nuclear propulsion plant are presented. This plant would be suited for tanker propulsion. Nitrogen was selected as the working fluid since it is relatively inexpensive, readily available and is chemically inert. At design point of 20,000 SHP the following conditions exist in the plant: gas enters the L. P. compressor at 115° F and 170 psia; enters the intercooler at 281° F and leaves at 115° F; enters the H. P. compressor and leaves at 263° F and 737 psia; enters the recuperator and is preheated to 773° F from L.P. turbine exhaust; enters the reactor and then to the H. P. turbine at 1300° F and 705 psia; from the H. P. turbine the gas enters the L. P. turbine at 1008° F and 307 psia and leaves at 830° F and 178 psia; then to the recuperator, the precooler and back to the L. P. compressor. The propulsion plant includes: a constant speed gas producer consisting of L. P. and H. P. compressors driven by a H. P. turbine; an intercooler between the compressors; a L. P. turbine which is geared to the propeller shaft. Starting, controls, cooling, installation, electric power generating equipment, reactor refueling, cost, weight, efficiency and pumping equipment are discussed.

70–57 "Some Aspects of the Application of Planned Maintenance to Marine Engineering"—W. H. Falconer; The Institute of Marine Engineers Transactions, v. LXIX, n. 2, Feb. 1957, pp. 37–58. Carefully planned maintenance can increase plant reliability and reduce operating costs. This is realized by elimination, as far as possible, of failures during operational periods when cost would be very high. Loss of a day's availability during overhaul is estimated at £400 to £5,000 depending on the size of vessel. Maintenance schedules can be effective if parts are examined at the end of their scheduled number of running hours. Recording machinery experience, collation of data and performance testing are important in maintenance program. Repair by replacement is attractive and the practice is expected to grow. Bibliography, charts, photographs and discussions.

NAME AND ADDRESS OF PUBLISHERS

The publishers, with addresses, of the periodicals from which the above abstracts were prepared are presented below. This information is provided for the convenience of readers of THE JOURNAL who wish to obtain complete copies of papers abstracted. The numbering system below corresponds to the abstract numbering system.

50–57 American Society of Lubrication Engineers
84 E. Randolph Street
Chicago 1, Illinois

51–57 Brown-Boveri & Co., Ltd.
Baden, Switzerland

52–57 Machine Design
Penton Building
Cleveland 13, Ohio

53–57 The Royal Aeronautical Society
4 Hamilton Place
London, W. I., England

54–57 North East Coast Institute of Engineers & Shipbuilders
Newcastle-upon-Tyne
England

55–57 Whitehall Technical Press, Ltd.
9 Catherine Place
Westminster
London, S. W. I., England

56–57 Temple Press Ltd.
Bowling Green Lane
London, E. C. I., England

57–57 Butterworth Scientific Publications
88 Kingsway
London, W. C. I., England

58–57 General Electric Co.
Schenectady 5, N. Y.

59–57 Reinhold Publishing Corp.
430 Park Avenue
New York 22, N. Y.

60–57 The Shipbuilder & Marine Engine-Builder
Townsville House,
274 Heaton Road
Newcastle-on-Tyne, 6, England

61–57 The Gage Publishing Co.
1250 Sixth Avenue
New York 20, N. Y.

62–57 McGraw-Hill Publishing Co.
330 W. 42nd Street
New York 36, N. Y.

63–57 Metropolitan-Vickers Electrical Co., Ltd.
Trafford Park
Manchester 17, England

64–57 The American Society of Mechanical Engineers
29 West Thirty-Ninth Street
New York 18, N. Y.

65–57 The Engineer
28 Essex Street, Strand
London, W. C. 2, England

66–57 The American Chemical Society
20th and Northampton Streets
Easton, Pennsylvania

67–57 The Bristol Aeroplane Co., Ltd.
Filton House
Bristol, England

68–57 American Society of Tool Engineers
239 E. Chicago Street
Milwaukee, Wisconsin

69–57 Temple Press, Ltd.
Bowling Green Lane
London, E. C. 1, England

70–57 The Institute of Marine Engineers
85 Minories
London, E. C. 3, England

BOOK REVIEWS & NOTICES

ENGINEERING THERMODYNAMICS

by

C. O. Mackey, W. N. Barnard, and F. O. Ellenwood
Published in 1957 by John Wiley & Sons, Inc. 428 Pages. Price: $7.95. Reviewed by Professor Arthur E. Bock, Department of Marine Engineering, U.S. Naval Academy

Chapter one traces the development of heat engine power from the steam turbine of Hero of Alexandria in 120 B.C. through the more recent accomplishments of Parsons and de Laval. The progress of power from heat is traced through the developments of Savery, Newcomen, Watt, Hornblower, Trevithick, Stephenson, Fitch, Fulton, Stevens, Corliss, Sweet, Parsons and de Laval. All the former were involved either in fundamental improvements or refinements in the field of steam engines and turbines. Similarly, development of the internal combustion engine from its earliest known form through the improvements of Lenoir, Otto, Priestman, Stuart and Diesel are chronologically related. Finally, the gas turbine, the jet engine and the nuclear power plant are discussed in both present and proposed applications.

Chapter two defines a thermodynamic system, thermal equilibrium, the First Law of Thermodynamics and the fundamental concepts necessary to evaluate the changes undergone by a thermodynamic system. Properties of state, processes, cycles, heat and work, mass and energy, stored energy, internal energy and flow work are either defined, described at length, or compared by analogy.

Chapter three introduces reversibility as the result of maintaining a progression of equilibrium states. In developing the non-flow energy equation and defining work as the $\int pdv$, the author is thorough and meticulous in establishing boundaries and limitations. The difference between specific heat at constant volume and that at constant pressure is discussed, but the explanation lacks both mathematical and descriptive clarity. Enthalpy is defined and its relationship to the constant pressure process is noted. Non-flow and steady flow energy equations are immediately associated with typical applications and one example of an unsteady flow situation is offered.

Chapter four is a rather extensive coverage of the second law of thermodynamics, heat engines and heat pumps, reversibility, irreversibility and the Carnot cycle, thermodynamic scale of temperature, thermal efficiency, coefficient of performance, entropy, available energy and maximum and minimum work. This material, along with the development of the Maxwell relations, coefficient of expansion equations and the Joule-Thompson coefficient in chapter five lay a strong foundation for the analysis of any type of thermodynamic system.

It is the writer's impression that in the early pages of chapter four, a few more diagrams of the p-v, T-s type would powerfully assist the theoretical discussion. The coverage of fundamentals in both chapters two and four is extensive and exact.

Chapter six discusses the characteristics and behavior of gases. Utilizing Boyle's law and Charles' law the relationship between the absolute and relative scales of temperature measurement is deduced and the perfect gas equation of state derived. In the majority of engineering problems, the properties of real gases at low pressures may be approximated by the perfect gas equation of state. However, in certain applications, particularly at high pressures and low temperatures, the assumption that a real gas or vapor will obey the perfect gas equation of state is not sufficiently precise. Consequently, to describe the behavior of these real (imperfect) gases and vapors over a complete range of pressures and temperatures, the van der Waals and Beattie-Bridgeman equations of state are introduced and explained in detail. The author also discusses the feasibility of extending the range of applicability of the perfect gas equation of state by the use of compressibility correction factors. The values of the constants for various working substances for the van der Waals and Beattie-Bridgeman equations of state are presented in convenient tabular form; however, the reader is left to his own devices to ascertain the numerical value of the compressibility correction factor. In this connection, the inclusion of generalized compressibility charts, such as those utilized by H. C. Weber in

"Thermodynamics for Chemical Engineers," presenting the compressibility correction factor as a function of the reduced pressure and reduced temperature would be most helpful.

On the basis of the kinetic theory of gases, the classical relationships for enthalpy and internal energy are introduced and developed in differential form. The perfect gas equations and energy relationships are further used to develop methods for evaluating the change of entropy in any process. An excellent feature of this chapter that is not commonly found in engineering thermodynamics texts is an extensive explanation of the variation of specific heat with temperature from the kinetic theory viewpoint. Utilizing spectroscopic data, empirical relationships are presented for computing the specific heat of gases at low temperatures.

Chapter seven is an excellent presentation of steady, one-dimensional, compressible flow of perfect gases. Treating first isentropic flow with area variation, and utilizing the perfect gas relationships and the conservation of mass and energy, the author derives Euler's equation and introduces the concepts of isentropic stagnation temperature and isentropic stagnation pressure. Combination of the Euler equation and the continuity equation leads to the identification of the critical conditions and to the development of equations for the computation of the critical flow characteristics. Classical discussions of adiabatic flow with friction and frictionless flow with heat transfer are lucidly presented. In developing the equations for the Fanno and Rayleigh lines, the author places particular emphasis upon previously developed perfect gas relationships and the fundamental concepts of the conservation of mass and energy. The discussion of steady, one-dimensional flow of perfect gases concludes with a brief treatment of flow discontinuities. The nature of the compression shock wave and the variation of the fluid properties across the compression shock wave are discussed. Appropriate equations are presented for the computation of the fluid properties across the normal compression shock wave as a function of the Mach number.

Chapter eight presents gas mixtures from a physical-thermodynamic viewpoint laying the basis for further studies in phase and chemical equilibria and reaction kinetics. The usual developments and proofs of partial pressure relationships and the intensive properties, i.e., apparent gas constant (R), internal energy, specific heat, and entropy of gas mixtures is included in the treatment. Special emphasis is given to the air-water system which includes the psychrometric vocabulary and considerable sample problem work. Compression and expansion of gas mixtures and specifically the air-water system are discussed. The effect of mixing on the Gibbs Function is presented. As introduced, the Gibbs Function seems to appear here mainly to plague the already belaboured student as the application of the function does not appear in later chapters. In the interest of standardization, it would seem advisable to use standard abbreviations. Gibbs first identified this function by the Greek letter sigma and called it free energy. Lewis and Randall used the symbol "F." Other texts employ "G." Prof. Mackey reaches the alphabetical end by calling it "Z." The only criticism offered is the appearance of certain constants and relations which have been in active use for many pages without identification.

Chapter nine, entitled "Ideal Gas Reactions" covers stoichiometric calculations presented via sample problems and dwells on thermochemistry, chemical equilibrium, and the evaluation of gas phase equilibrium constants based on the Third Law of Thermodynamics for gaseous systems at various temperatures. This section ends with a method to calculate adiabatic flame temperatures. It is the opinion of this writer that much of the material presented would be of limited interest to engineers outside the field of chemistry. This chapter is meticulously written. Assumptions and restrictions of proofs are emphasized.

Air compressors are discussed in chapter 10. Reciprocating compressors are discussed in the classical manner and a study of axial and centrifugal type compressors is undertaken with vector and momentum analyses. Drawings, operating pressures and capacities of industrial type compressors are included.

The topic of gas power cycles is introduced by a review of the cyclic concept and a discussion of the mean effective pressure. In successive order the author thoroughly covers air engine cycles, the Carnot cycle, the Otto cycle, the Diesel cycle, the dual combustion cycle, the Stirling and Ericsson cycles and the Brayton cycle.

For a piston engine, a high mean effective pressure indicates that the engine will deliver high torque per unit of size, thus permitting a low initial cost for an engine of a given power output. The thermal efficiency is indicative of the cycle output per unit of fuel consumed. Thus, comparing engines burning fuels of approximately equivalent cost, a high thermal efficiency is indicative of an economical engine from the fuel cost viewpoint. For each cycle considered, equations for the mean effective pressure and the cycle thermal efficiency are developed, thus accomplishing a direct comparison on the basis of these parameters. An excellent example of a cycle energy balance is presented for an open Otto cycle, and a numerical comparison of the air-standard and real-mixture standard is afforded.

Particular attention is devoted to the family of air breathing thrust producing engines operating on the Brayton cycle. The thermodynamic and propulsive aspects of ram jets, pulse jets, and turbo jets are discussed along with certain elements of rocket propulsion. At the conclusion of the chapter the author indulges in a brief discussion of the effects of such innovations as staging, intercooling, regenerative heating, and reheating upon gas turbine performance.

The presentation on the properties of vapors is in the classical manner using a heat addition process in a cylinder with weighted piston. Saturated liquid and vapor lines are established on pressure-specific volume and temperature-entropy coordinates and all following discussion on specific properties is based on these diagrams. Basic equations for property changes are also given and tied in with the diagram material. Phase diagrams on the relationship of vapors to solids as well as liquids are included. The handling of vapor problems by both steam tables and charts is illustrated with particular emphasis on the Ellenwood or enthalpy-specific volume charts. Typical processes are illustrated by the use of sample problems enabling the student to trace the method of solution clearly. The particular processes of conversion to kinetic energy in a nozzle and throttling in a calorimeter, both sources of difficulty to many students, are covered in considerable detail including a good discussion of the types of nozzles and calorimeters in use.

In chapter thirteen, energy transformation in turbines is approached both from impulse and momentum principles using vector force analysis and from thermodynamic reasoning involving energy relationships. The two methods are well tied together through discussion and diagrams. Enough material on staging, axial versus radial flow, and actual turbine types is presented to form a good basis for more advanced study.

The material on power cycles of vapors emphasizes, as is to be expected, those cycles employing steam as the working substance. The basic Carnot cycles for vapors are briefly discussed along with theoretical methods of obtaining these cycles, but the chapter deals primarily with the Rankine cycle and its various modifications. This discussion is presented in considerable detail and uses excellent equipment and temperature-entropy diagrams to clarify the various Rankine processes. Both ideal and actual cases are considered. A good general description of binary vapor cycles is included with appropriate diagrams and this leads into a section on simple atomic reactor cycles. While brief, this section could again form a basis for more advanced work by the interested student.

Chapter fifteen provides a rather complete treatment of refrigeration for a basic thermodynamic text. After using the standard of ideal performance, the reversed Carnot cycle, to introduce refrigerating terms and definitions, six difierent practical systems are covered in sufficient detail to permit problem solution. The various properties of the common refrigerants are listed and discussed. Mollier type charts for ammonia and aqua ammonia are included but the student is left to search out handbook data on the common Freon refrigerants.

This rather lengthy analysis of each section of the book emphasizes the individual strong and weak points from this writer's viewpoint. Overall comment must indicate that the book has been carefully written, well organized, and generally well illustrated. As a text book it would probably best be described as comprehensive. As a reference book, it contains sufficiently wide coverage to make it most desirable.

THE SCIENCE OF ENGINEERING MATERIALS

Edited by
J. E. Goldman
Published by
John Wiley and Sons
510 pages $12.00

This book contains 18 papers each of which was written by a scientist who is outstanding in the subject discussed. The papers were lectures on the impact of Solid-State Science on Engineering Materials, based on the Proceedings of the Carnegie Conference held at Carnegie Institute of Technology in June 1954.

The Conference was held for a discussion of recent technical developments in solid-state science and to explore ways and means of including these in engineering curricula.

The time has come or nearly so, when the engineer will not go to the shelf for materials to which he must adapt his designs. Instead he will specify the materials which he will require and will call on the science of the solid-state to "design and manufacture" them to his specifications. Under this condition it is essential that, in his basic education, the student engineer learn much about the solid-state.

The Conference consisted principally of educators who visualized the need and faced the problem of how to merge the *science* of the solid-state with the other knowledge which an engineer requires. The book places before the reader, the science of the solid-state so that he who reads will appreciate the problem and be in a position, as circumstances permit, to spread the word as to the basic need of solid-state knowledge to the engineer of today and tomorrow.

The book is arranged into six Parts. In these the papers are grouped by subject matter. A list of the Parts, the subjects and the authors should be suffi-

cient to prove the real worth of the book and its real value to engineers and scientists alike. These are:

Part I. The Structure of Matter

1. Applications of Solid-State Science in Engineering: An Introductory Survey
   By Harvey Brooks, Gordon McKay Professor of Applied Science, Harvard University.
2. Structure of Atoms and Atomic Aggregates
   By John Bardeen, Professor of Theoretical Physics and Electrical Engineering, University of Illinois; Nobel Laureate in Physics 1956
   W. Bitler, Assistant Professor of Metallurgical Engineering, Carnegie Institute of Technology
   J. E. Goldman, the Editor, Manager, Physics Department, Scientific Laboratory, Ford Motor Company.
3. Accomplishments and Limitations of Solid State Theory
   by Harvey Brooks.
4. Crystal Imperfections
   By John Bardeen.

Part II. Metals and Alloys

5. The Metallic State; Theory of Some Properties of Metals and Alloys
   By Roman Smoluchowski, Professor of Physics, Carnegie Institute of Technology.
6. Electron Theory of Alloy Formation and Elastic Properties
   By Harry Jones, Professor of Mathematics, Imperial College, London.
7. Dislocations in Solids
   By Roman Smoluchowski.
8. Dislocation Theories of Mechanical Properties
   By Harry W. Paxton, Assistant Professor of Metallurgical Engineering, Carnegie Institute of Technology.
9. Experimental Evidence for Behavior of Dislocations
   By Earl A. Parker, Professor of Metallurgy and Chairman, Division of Mineral Technology, University of California.
10. Phase Transformations in Metals and Their Influence on Mechanical Properties
    By T. A. Read, Professor and Head of Department of Metallurgical Engineering, University of Illinois.

Part III. Surfaces

11. Surface Phenomena
    By Robert Gomer, Associate Professor, Institute for Study of Metals, University of Chicago.

Part IV. Magnetism and Magnetic Properties

12. The Theoretical Basis of Magnetic Phenomena
    By J. E. Goldman.
13. The Physics of Magnetic Materials
    By R. M. Bozorth, Member of the Technical Staff, Bell Telephone Laboratories.

Part V. Semiconductors and Dielectrics

14. The Physics of Semiconductors
    By K. Lark-Horovitz, Professor and Head of Department of Physics, Purdue University, and
    V. A. Johnson, Professor of Physics, Purdue University.
15. Semiconductor Devices
    By E. M. Conwell, Research Physicist, Sylvania Electric Products Company, and
    W. J. Leivo, Professor of Physics, Oklahome A & M College.

Part IV. Non-Crystalline Materials

16. Some Aspects of the Physics and Chemistry of Cement
    By Stephen Brunauer, Senior Research Scientist, Portland Cement Association.
17. Molecular Structure and Mechanical Behavior of High Polymers
    By Turner Alfrey, Jr., Director Polymer Research Laboratory, Dow Chemical Company.
18. The Physics of Glass
    By T. Harrison Davies, Director, Pittsburgh Plate Glass Fellowship, Mellon Institute.

BRITTLE BEHAVIOR OF ENGINEERING STRUCTURES

by
Earl R. Parker
Published in 1957 by
John Wiley & Sons, Inc.
440 Fourth Avenue, New York 16, N. Y.
323 Pages Price $6.00

This book was prepared for the Ship Structure Committee under the general direction of the Committee on Ship Steel, National Academy of Sciences —National Research Council. It summarizes the available information on the brittle behavior of steel in engineering structures. It contains a discussion of

the theories and mechanism of failure, a review of test methods used for evaluating relative brittleness, interpretations and summaries of test results, a discussion of the effects of welding composition variations on notch toughness, and a report of service failures.

HIGH-SPEED SMALL CRAFT

by
Peter DuCane
Second Edition published in 1957 by
Philosophical Library, Inc.
15 East 40th Street, New York 16, N. Y.
324 pages Price $15.00

This revised edition provides more basic theoretical material than did the first edition. Several new chapters are included: The Principles Underlying the Performance of Planing Craft in Theory and Practice; Rudder Design in Plan Form and Section; Reinforced Plastics for Boat-building; Light Alloys in High-Speed Craft; Propelling Machinery; and Use of Models for Prediction of Behavior in Rough Water.

CARGO SHIP LOADING

by the
MARITIME CARGO TRANSPORTATION CONFERENCE
Published in 1957 by
National Academy of Sciences—National Research Council
91 pages

This analysis of general cargo loading operations in selected ports of the United States was undertaken on the recommendation of members of the Board of Advisors of the Maritime Cargo Transportation Conference (MCTC) of the National Academy of Sciences—National Research Council. The "Cargo Ship Loading" study is a sequel to the *"SS Warrior"* study, in which cargo ship loading was isolated as one of the general cargo transportation process segments most susceptible to significant improvements.

The loading study analyzes in detail the loading process in various U. S. ports and shows the extent to which the present break-bulk system is operating below its capability. It also identifies and evaluates the gains in productivity which can be achieved by certain technical improvements which do not involve a change in the basic system. The results are intended to provide a quantitative basis for future comparisons of the existing break-bulk loading system with unconventional loading systems under consideration by the maritime industry. The importance of the human relations problem became very apparent when attempts were made to isolate and identify the causes of observed inefficiencies in the current utilization of machinery and manpower.

THE CASTING OF STEEL

Edited by
W. C. Newell
Published in 1957 by
Philosophical Library, Inc.,
15 East 40th Street, New York 16, N. Y.
599 pages Price $27.50

According to the editor, Dr. Newell, who was formerly Head of Steel Castings Division, British Iron and Steel Research Association, this book is intended for skilled foundry workers, engineers responsible for designs incorporating steel castings, designers of foundry equipment, and metallurgical students wishing to specialize in foundry work.

Profusely illustrated, this book contains 13 chapters, with headings as follows:

1. Properties of the Liquid Metal
2. The Mechanism of Solidification
3. The Melting Process
4. The Use of Refractories
5. Pattern Making
6. Mold Preparation and Core Making
7. Casting into Sand Molds
8. Centrifugal Formation of Castings
9. The Investment Casting Process
10. The Heat Treatment and Properties of Steel Castings
11. Mechanical Testing, Physical Properties, Specifications
12. Radiography
13. Non-Destructive Testing (Methods other than Radiography)

REAR ADMIRAL JOSEPH JOHN BROSHEK, U.S.N., (Retired)

On Sunday, the second of June, 1957, Rear Admiral "Joe" Broshek, the Society's 36th President, died at the Naval Hospital in San Diego, California.

Admiral Broshek graduated from the Naval Academy in 1908. In 1915, after having served at sea in conventional billets for five years, he completed a two-year post graduate course and received the Master of Science degree from Columbia University. His specialty was electrical engineering.

When Congress authorized the special designation of Engineering Duty Only, Admiral Broshek was among the earliest naval officers who were selected and designated as "E.D.O." During World War I he served as Engineering Officer on the transport USS George Washington. Thereafter he filled many important engineering posts, including duty at the Brooklyn Navy Yard, the Post Graduate School at Annapolis and the Bureau of Engineering in the Navy Department.

During World War II Admiral Broshek served as Head of Ship Maintenance in the Bureau of Ships, which shortly before had succeeded the Bureau of Engineering in which he had contributed so much during the years between the wars. For outstanding work as Head of Ship Maintenance, Admiral Broshek was awarded the Distinguished Service Medal.

Admiral Broshek, at the time of his death, had been a member of the American Society of Naval Engineers for 42 years, having joined on 16 March, 1915, while receiving his postgraduate education. In 1942 he was elected to serve as President of the Society during 1943, which he did with distinction. He was one of our war-time presidents who, in spite of very pressing official duties and, in the face of material shortages and interfering priorities, kept the Society going and growing, and maintained the Journal without a single lost or delayed issue.

Admiral Broshek's wife predeceased him by several years. During a long illness before his death, he lived with a niece, Mrs. Lillian B. Rose of Santa Ann, Calif.

Admiral Broshek was buried on 6 June, 1957, in the National Cemetery at Fort Rosecranz in San Diego.

Captain C. S. McDowell, U.S. Navy, Retired

On Thursday, 18 July 1957, Captain C. S. McDonald, U.S. Navy, Retired, at the age of 72, died in Hillsborough, Calif. Captain McDowell had been a member of the Society for 43 years, continually since joining on 4 February 1914. Captain McDowell graduated from the U.S. Naval Academy in 1904. Among his achievements were the establishment of the Submarine School at New London, Conn., in which he had a part; and the installation of the great telescope at Mount Palomar in California for which he was the Engineer in Charge.

It becomes the sad duty of the Society to announce the death of the following:

Broshek, Joseph J., Naval Member

Champlain, Harry Perry, Civil Member

Cheyney, Charles C., Civil Member

Gordon, Curtis A., Civil Member

Lefebvre, Gordon, Civil Member

McDowell, C. S., Naval Member

Thau, W. E., Associate Member

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

It is with much pleasure that the Society announces the following additions to its membership since the publication of the May, 1957 Journal:

NAVAL

Alfano, William A., Jr., Lieutenant j.g., U.S.N.R.
CONVAIR
Mail: 1032 Calaveras Drive, San Diego 76, Calif.

Anderson, Joseph Clary, Commander, USNR
Sales Manager, Industrial Products Div. Boeing Airplane Co.
P.O. Box 3707, Seattle 24, Wash.

Barrett, James M., Lieutenant, USCG
The Babcock & Wilcox Co., Atomic Energy Div., Lynchburg, Va.

Boehm, William Robert, Commander, USN
Industrial Manager, 10th Naval District, c/o Fleet P.O., New York, N.Y.

Borkas, Richard Edward, Lieut. j.g., USNR
Engineer, Bethlehem Steel Co., Shipbuilding Div.
Mail: 42 Dearborn St., Medford 55, Mass.

Brice, John Eldred, Lieutenant, USN, Electronics Engineer, Bureau of Aeronautics, Navy Dept.
Mail: 5821 Atteentee Road, Springfield, Va.

Bryant, John Dixon, Lieutenant, USN
Mail: c/o E. S. Metcalf, Damariscotta, Me.

Cline, Ford Robert, Captain, USNR, Supervising Engineer, Bureau of Ships, Navy Dept.
Mail: 2609 N. Nottingham St., Arlington 7, Va.

Coutre, Clarence, Jr., Lieutenant, USN
Charleston Naval Shipyard, Charleston, S.C.

Culver, John Arthur, Lieutenant, USNR, Marine Engineer, Bureau of Ships, Navy Dept.
Mail: 1001 Gilbert St., Rockville, Md.

D'Entremont, Richard L., Lieutenant j.g., USN
USS GILLIGAN (DE 508) c/o Fleet P.O., San Francisco, Calif.

DeLuca, Joseph D., Commander, USN
Mail: 5626 Regia St., San Diego, Calif.

Edelson, Burton I., Lieutenant, USN
Supervisor of Shipbuilding
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Hansen, Corwin A., Commander, USNR
Airborne Instruments Laboratory, Inc.
Mail: Bobehan Court, RFD 5, Huntington, N.Y.

Hardy, Richard, Lieut. Commander, USNR
General Electric Co., 777 14th St., N.W., Washington, D.C.

Harris, Lyman Charles, Lieutenant, USN
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Hohenstein, Clyde Gilbert, Ensign, USN
USS STEPHEN POTTER (DD 538),
c/o Fleet P.O., San Francisco, Calif.

Kommers, William James, Lieutenant, USNR, Ret.
Head, Fuels & Lubricants Branch, Internal Combustion Engine Laboratory
Engineering Experiment Station, Annapolis, Md.
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Louchheim, William S., Lieutenant, USN
USS ETLAH (AK 79), c/o Fleet P.O., San Francisco, Calif.

Lutken, Donald Curry, Ensign, USNR
Plant Supt., Delta Steam Electric Station
Box 1071, Cleveland, Miss.

MacLean, Jay Robert, Lieutenant, j.g., USN
Mail: 1428 South Cedar St., Spokane, Wash.

Morgan, Warren F., Commander, USNR
Federal Electric Corporation, P.O. Box 34, Lodi, N.J.

Myers, Jacob Christian, Captain, USN
213 Prince St., Alexandria, Va.

Nichols, Robert Howard, Ensign, USN
Pearl Harbor Naval Shipyard, Repair Div. Bldg. 24, Navy 128
c/o Fleet P.O., San Francisco, Calif.

Ogden, Edward George, Lieutenant, j.g., USN
USS GLENNON (DD 840) c/o Fleet P.O., New York, N.Y.

Piersall, Charles Homer, Ensign, USN
USS GILLIGAN (DE 508) c/o Fleet P.O., San Francisco, Calif.

Richardson, William Harrell, Captain, USNR
The Ramo Corp., 1300 Connecticut Ave., N.W., Washington 6, D.C.

Riley, William John, Lieutenant, USNR, Ret.
Supervisor, Ira S. Buchey & Sons, Inc.
Mail: 8105 Fourth Ave., Brooklyn 9, N.Y.

Sholl, Samuel Alfred, Commander, USNR
RD No. 1, Georgetown Road, Bordentown, N.J.

Swebson, Erick N., Lieutenant, USNR
Code 810, B2, Bureau of Ships, Navy Dept.
Mail: BOQ, US Naval Receiving Station, Washington, D.C.

Vorhaben, William Soland, Ensign, USNR
122 Delashaise St., New Orleans 15, La.

Walter, Alfred H., Lieutenant, j.g., USCG
22 Cambridge Road, Norwood, Mass.

Walton, Robert J., Lieutenant, USNR
Manager, Marine Dept., Electro Rust Proofing Corp.
Main St., Belleville 9, N.J.

Wynne, Donald Malcolm, Lieutenant, USN
USS WARRINGTON (DD 843), c/o Fleet P.O., New York, N.Y.

CIVIL

Albright, Albert A., Asst. Manager, Marine Sales
The Cooper-Bessemer Corp. P.O. Box 751, Mt. Vernon, Ohio

Barrie, Stanley P., Project Engineer, H. K. Ferguson Co.
Mail: Wander Inn Trailer Court, Route 33, Barahoo, Wis.

Berendsen, Raymond C., Manager, Engineering, Missile and Ordnance Systems Dept., Ordnance Section, Ordnance Systems Dept., General Electric Co. M&Os, Pittsfield, Mass.

Hampton, John K., Washington Representative, Detroit Diesel Div., GMC., 1625 Eye St., N.W., Washington, D.C.

Harvey, John F., Engineering Section Head
Babcock & Wilcox Co., Barberton, Ohio

Leven, Samuel, Chief Engineer, Industrial Compressors, Joy Mfg. Co., Michigan City, Ind.

Lynn, George Francis, Manager of Ship Sales, New York Shipbuilding Corp.
Mail: 125 Colwick Road, Merchantville 8, N.J.

Schutter, Carl Wilhelm, Chairman of the Board, Carl W. Schutters Corp., 86 East Homtauk Highway, Lindenhurst, N.J.

Tempia, Louis
Marine Engineer, Bureau of Ships, Navy Dept.
Mail: 4408 2d St., N.E., Washington 11, D.C.

ASSOCIATE

Hall, William Purnell
President, Maryland Shipbuilding & Dry Dock Co., P.O. Box 537, Baltimore 3, Md.

Harris, George K.
Manager, sales, Light Military Electronic Equipment Dept. General Electric Co.,
French Road, Utica, N.Y.

Jory, William H.
Senior Vice President, Maryland Shipbuilding & Dry Dock Co., P.O. Box 537
Baltimore 3, Md.

Marsh, John Urie
Manager, Maxim Marine Laboratory
Mail: Millstone Point, Waterford, Conn.

Martinson, Albert Mathias, Jr.
Design Engineer, Dravo Corp.
Mail 1221 Grouse Drive, Pittsburgh 16, Pa.

REJOINED

Gerber, Henry L., Civil Member

RESIGNED

Lancaster, Frederick G., Jr., Associate Member

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

ASSOCIATION NOTES

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NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

We have a new supply of lapel buttons, in the form of the Society's official seal. These may be purchased by any member for fifty cents ($0.50) each.

By decision of the Council the official coloring of the Society seal is as it appears on the cover of this Journal. This is a reversal of the colors on the old lapel buttons. The size, one-half inch in diameter, remains the same.

Any member who wishes to exchange an old button for a new one may do so *free of charge*. Just send in the old button with your name and address.

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d) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

ASNE FINANCIAL STATEMENTS 1955

STATEMENT OF INCOME AND EXPENDITURES

EXPENDITURES

Publication:		
Printing	$21,905.86	
Engraving	2,449.68	
Manuscript	5,887.50	
Postage	902.02	
Commission and Discount	286.00	
Exchange	.38	$31,431.44
Salaries		12,686.10
General Expense		6,367.35
Bad Debts & Miscellaneous		1,687.50
Social Security		52.71
		$52,225.10

INCOME

Publication:		
Advertisements	$ 7,487.50	
Regular Dues	23,508.14	
Junior Member Dues	348.75	
Sales	338.16	
Subscriptions	14,409.75	
	$46,092.30	
Interest on Investments	1,425.00	
Banquet 1955	1,025.21	48,542.51
NET LOSS		$ 3,682.59

BALANCE STATEMENT

Assets January 1, 1955.			$64,644.88
Assets December 31, 1955:			
Cash		$ 4,500.70	
Petty Cash		200.00	
Accounts Receivable:			
Advertisements	$ 3,594.59		
Dues	1,742.60		
Sales	550.21		
Subscriptions	446.50	6,333.90	
Investments:			
U. S. Defense Bonds, Series G	$52,000.00		
Washington Gas Light Co. Bonds	997.50	52,997.50	
Furniture		2,008.39	
Banquet 1956		105.45	
Manuscript Paid in Advance		1,897.50	
		$68,043.44	
Liabilities (Accounting Only):			
Dues Paid in Advance	$ 360.65		
Subscriptions Paid in Advance	6,558.00		
Advertisements Paid in Advance	112.50		
Brand Award	50.00	$ 7,081.15	
Net Assets December 31, 1955			$60,962.29
NET LOSS			$ 3,682.59

Respectfuly submitted

J. E. HAMILTON, SECRETARY-TREASURER

This has been
Audited and Found Correct

ASNE FINANCIAL STATEMENTS 1956

STATEMENT OF INCOME AND EXPENDITURES

EXPENDITURES

Publication:		
Printing	$28,117.72	
Engraving	3,106.79	
Manuscript	6,304.87	
Postage	527.97	
Commission & Discount	2,353.30	$40,410.65
Salaries		14,428.78
General Expense		6,354.49
Bad Debts & Miscellaneous		1,313.68
Social Security		6.40
		$62,514.00

INCOME

Publication:		
Advertisements	$13,073.60	
Regular Dues	24,019.81	
Junior Member Dues	378.75	
Sales	563.51	
Subscriptions	15,100.75	
Exchange	.01	
	$53,136.43	
Interest on Investments	$ 1,294.00	
Banquet 1956	1,740.18	56,170.61
NET LOSS		$ 6,343.39

BALANCE STATEMENT

Assets January 1, 1956.			$60,962.29
Assets December 31, 1956:			
Cash		$ 1,099.75	
Petty Cash		200.00	
Accounts Receivable:			
Advertisements	$ 2,924.91		
Dues	1,828.82		
Sales	550.98		
Subscriptions	525.00	5,829.71	
Investments:			
U. S. Defense Bonds, Series G	$32,000.00		
Washington Gas Light Co. Bonds	997.50		
Perpetual Building Association	9,000.00		
Equitable Saving & Loan Association	10,000.00	51,997.50	
Furniture		2,620.68	
Insurance		113.45	
Manuscript paid in advance		715.00	
		$62,576.09	
Liabilities (Accounting Only)			
Advertisements paid in Advance	$ 165.00		
Dues paid in Advance	745.32		
Subscriptions paid in Advance	6,999.00		
Brand Award	41.00		
Social Security Tax	6.87	7,957.19	
Net Assets December 31, 1956			$54,618.90
	NET LOSS		$ 6,343.39

Respectfully submitted

J. E. HAMILTON, SECRETARY-TREASURER

This has been
Audited and Found Correct

APPLICATION FOR MEMBERSHIP

IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

(See reverse side for required qualifications for various classes of membership)

Date _____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $7.50 as my annual membership dues for the year _____ $6.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

For Naval Membership

Name _____
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Rank _____ File No. _____

Business connection and position, if any _____

For Civil Membership

Name _____
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Years in engineering work _____

Years in responsible charge of important work _____

Present business connection and position _____

Recommended by (two members) _____

_____

For Associate Membership

Name _____
(First) (Middle) (Last)

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MAIL TO SECRETARY-TREASURER
THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.
Suite 1004, Continental Building
1012 14th St., N.W.
Washington 5, D.C.

QUALIFICATIONS FOR MEMBERSHIP

Commissioned and ex-commissioned officers of the regular Navy, Marine Corps and Coast Guard of the United States; warrant and ex-warrant officers of the regular Navy, Coast Guard and Marine Corps of the United States; reserve commissioned and warrant officers of the Navy, Coast Guard and Marine Corps of the United States shall be eligible as Naval Members. Persons eligible as naval members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as civil members. They shall have been in active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as civil members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as associate members. Commissioned officers of the United States Army and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army and of foreign naval and military services, the recommendation of a member will not be required.

Associate members shall be entitled to all the privileges of other members except voting and holding office.

The annual dues shall be $7.50, payable on 1 January in advance, of which $6.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

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AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

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